Assessing the Petroleum Geology and Future Development of the Clendenin Gas Field in Kanawha County, West Virginia

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Major Department: Geological Sciences

Petroleum is one of the main sources for energy production in the US and is therefore important for the continuation of economic growth. Future development of petroleum resources in the US to meet supply demands is equally important. Understanding the controls on petroleum production will help in determining where and how to development these resources for maximum production. West Virginia is home to many gas fields and is underlain by one of the more prominent gas producing shales, the Marcellus Shale. The Clendenin Gas Field in Kanawha County is one of the historical gas producing areas found in West Virginia. This assessment is focused on the Devonian strata throughout the field including the Marcellus Shale.

Using available geophysical logs, production data, and historic well records obtained from the West Virginia Geologic and Economic Survey (WVGES), cross-sections, isopach maps, and structure contour maps were created to give a visual representation of the subsurface geology across the field. Construction of the cross-sections and maps in conjunction with production and well record data aided in the identification of controls influencing production throughout the field. Applying the findings of this assessment to future production may reduce costs and improve yields of future petroleum wells.

Results of this study indicate several options should be considered when planning for future production wells within the field. Target areas include the areas to the east of the field where formations tend to thicken. Areas nearest fault zones and anticlines, where the formations potentially have more fractured and fissured zones which may allow for easier extraction were also noted as potential development sites. The Marcellus Shale is a recommended target for future production based on the amount of production recorded from non-Marcellus containing wells, which produced on average half of what wells produced from the Marcellus Shale. Lastly, all wells within the study areas were recorded as being vertical wells. Horizontal wells in neighboring counties produce nearly double the amount of gas compared to shallower units, according to data from the WVGES Pipeline reporting system. It is recommended that horizontal well construction be considered for future wells within this field.

Assessing the Petroleum Geology and Future Development of the Clendenin Gas Field in Kanawha County, West Virginia

A Thesis

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In Partial Fulfillment of the Requirements for the Degree

Master of Science in Geology

by

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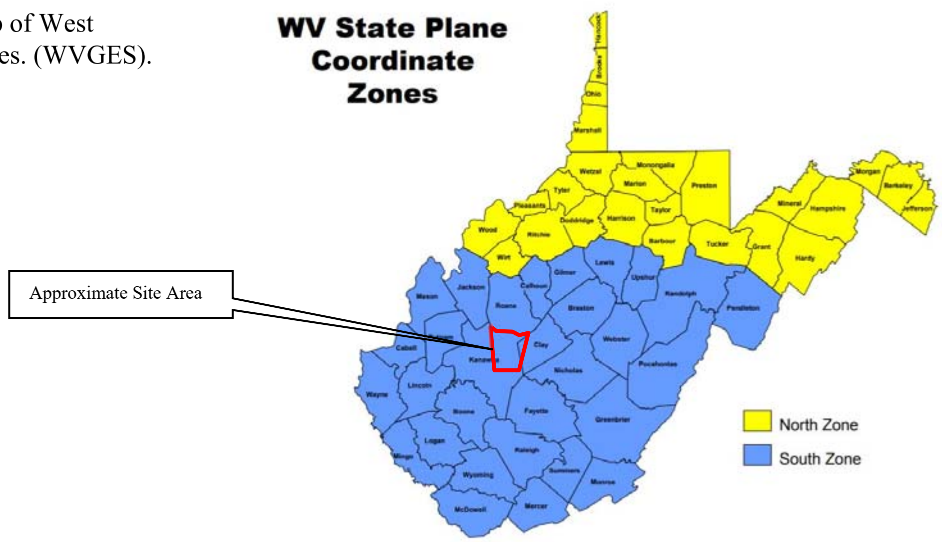
CHAPTER I: INTRODUCTION

The Clendenin Gas Field in Kanawha County is one of the historical gas producing areas found in West Virginia. Although data have been analyzed to determine areas of gas production, the area has not been looked at in the sense of future production potential from gas bearing formations that underlie the county. The purpose of this study is to examine the petroleum geology of the Devonian strata in the Clendenin Gas Field in West Virginia (Figure 1). The findings of this study will result in a guide for determining the most productive locations for development of wells for future gas production.

Figure 1: Map of West Virginia Counties. (WVGES).



Of special interest for this work is the potential for production from the Marcellus Shale, a Middle Devonian organic-rich shale, that has seen much interest and development in the past twenty years. After initial forays into the Clendenin field area, interest has waned (Kelso, 2012) and for this study an analysis of the controls on existing production and the potential for renewed development will be accomplished.

West Virginia encompasses three physiographic regions (Figure 2). From east to west, these are the Blue Ridge Physiographic Province, which contains some of the oldest exposed formations in the state, the Valley and Ridge Province, composed of folded and faulted rocks, and the Appalachian Plateau Province comprised of generally flat-lying rocks (wvgs.wvnet.edu). The Valley and Ridge Province and the Appalachian Plateau Province make up a majority of the state and is separated by a complex and abrupt change in the characteristic of the strata. This zone of change is known as the Allegheny Front. The Blue Ridge Province located to the northeastern most portion of the state makes up a small portion of the state and is separated from the Valley and Ridge Province by the Great Valley Sub-province. A second sub-province, the Allegheny Mountain Section, is located to the northeast between the Appalachian Plateau province and the Valley and Ridge Province (wvgs.wvnet.edu).

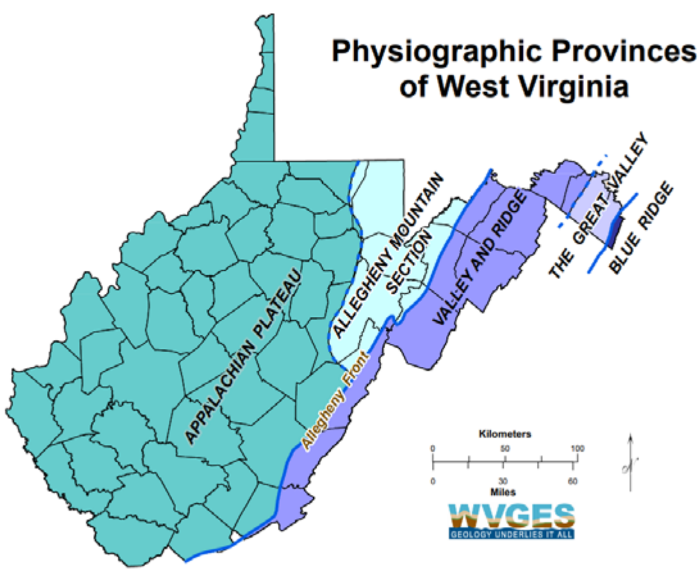


Figure 2: Physiographic Province map of West Virginia. Obtained from the West Virginia Geologic and Economic Survey (WVGES).

The study area underlies Kanawha and Clay counties, West Virginia, in the Appalachian Plateau Province. The deposition of petroleum-producing formations in this study area occurred from the Silurian to the late Pennsylvanian. The Clendenin Gas Field includes approximately six gas-bearing intervals (Figure 3) which include the Pennsylvanian and upper Mississippian clastics, Mississippian Greenbrier carbonates, the lower Mississippian and upper Devonian clastics, the Middle Devonian Marcellus Shale and the deeper Lower Devonian Oriskany Sandstone, Devonian-Silurian Helderberg carbonates and Lower Silurian Tuscarora Sandstone.

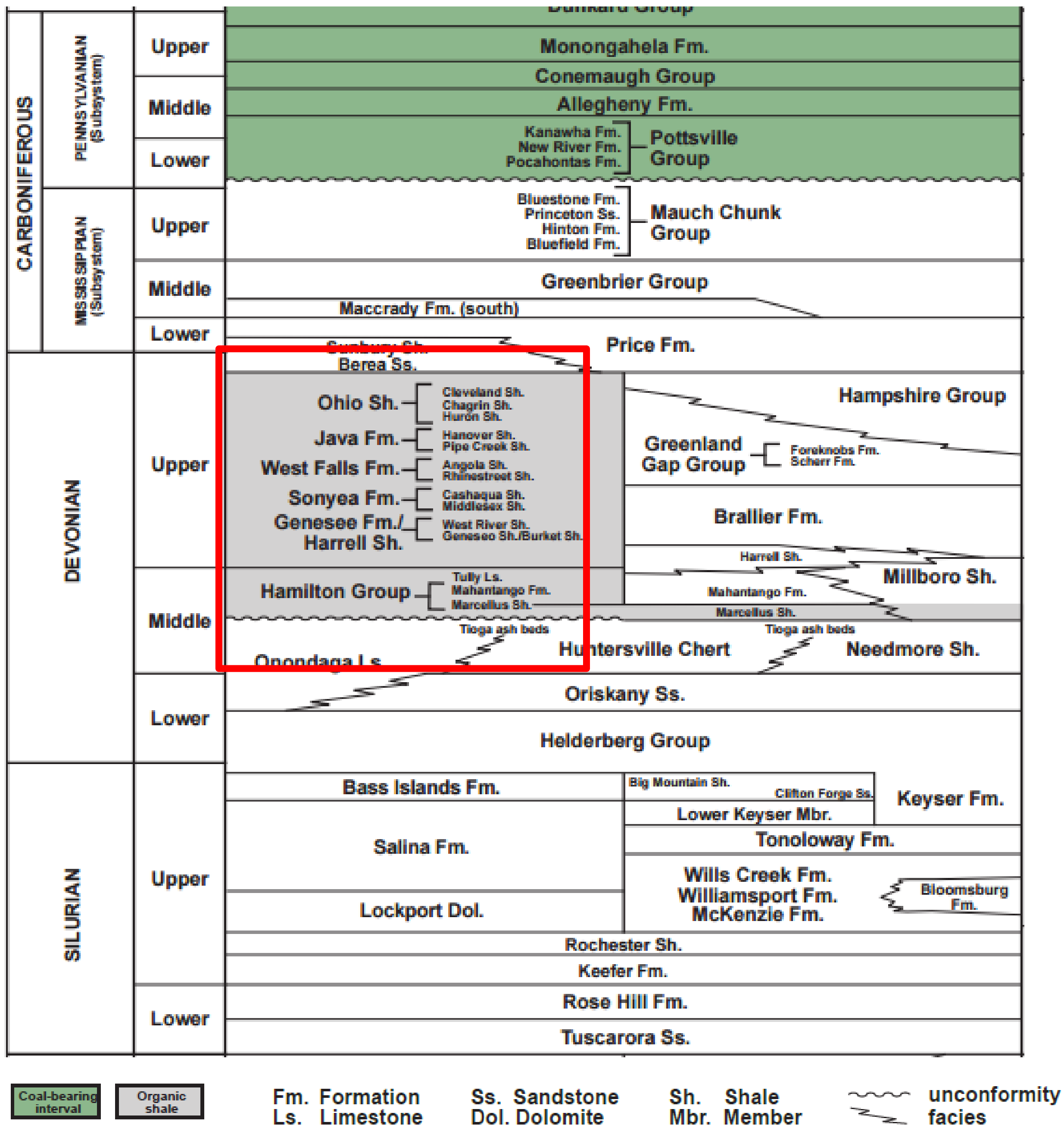


Figure 3: Generalized stratigraphic Chart of West Virginia (Obtained and adapted from WVGES Map 29a.) Area of interest for this study outlined in red.

CHAPTER II: BACKGROUND

Geologic Setting

During the late Proterozoic and into the Paleozoic, a shallow sea, Iapetus, covered most of West Virginia. This area covered by the Iapetus ocean is located within the Appalachian foreland basin which is a downwarped region which spans from northern Alabama into southern Canada and is approximately 330 miles in width at its widest point (Colton 1970) (Figure 4).

Figure 4: Approximate location of the Appalachian foreland basin is outlined in red. Obtained from SEPM Strata.

The basin, which was a retroarc foreland basin, beginning in the late Cambrian experienced episodes of subsidence followed by a period of influx of sediment from the neighboring orogenic chains parallel to the basin (Colton 1970). The sediments that filled the basin during the Precambrian consisted of marine carbonates, non-marine clastics, and evaporites (WVGES). The sediments that filled the basin are now the limestones, sandstone, siltstones, and shales that we explore for commercial hydrocarbon production.

Tectonic Setting

Prior to and during the time of deposition of the Middle to Upper Devonian formations several tectonic events occurred that influenced the structure throughout the area. Rifting during the late Neoproterozoic at the time of the fragmentation of Rodinia led to the formation of the Iapetus Ocean which covered a majority of the area where the Appalachian basin would later form (McDonald et. al., 2014; Gao et. al., 2000). The development of the sea over the basin allowed for infill of the basin with the marine and clastic sediments. In the Middle Ordovician to the Silurian the occurrence of the Taconic Orogeny, where the obduction of arc and oceanic materials onto the Laurentian margin (Hatcher, 2005), provided the main source of sediment during the Silurian and early to middle Devonian.

During the Middle to Late Devonian the Acadian Orogeny provided further deposition of marine sediments into the basin from the uplifted areas to the northeast. In the late Devonian the shallow sea began a westward retreat which resulted in the formation of the Hampshire Formation which generally consisted of red non-marine shales and micaceous sandstones (WVGES). The shallow sea once more intruded the area during the Mississippian followed by another retreat. Subsidence during the Pennsylvanian Period occurred with deposition occurring at a roughly equal rate (Ettensohn, 2008).

Structure

Deposition of sediment in the study area was not only affected by uplift and subsidence, but also by the structure of the basement underlying the area. Kanawha County is largely underlain by the Rome trough. The trough is a normal-fault-bounded graben which trends to the northeast and extends through the central Appalachian Basin (Gao et al., 2000) and formed during the rifting and fragmentation of Rodinia. The Rome trough contains faults, several of which transect the study area. The main fault that played a factor in the deposition in the study area is the East-Margin fault along with the Warfield Anticline (Thomas, 1991; Gao et al., 2000). The East-Margin fault transects the southeastern portion of the study area and runs from the southwest to the north as depicted in Figure 5. Note several additional unnamed faults transect the site. The faults may bound troughs in which the sediment may be deposited thicker atop the hanging walls (Gao. et. al., 2000). The troughs of thicker sediments may be target areas for production wells since they contain thicker beds.

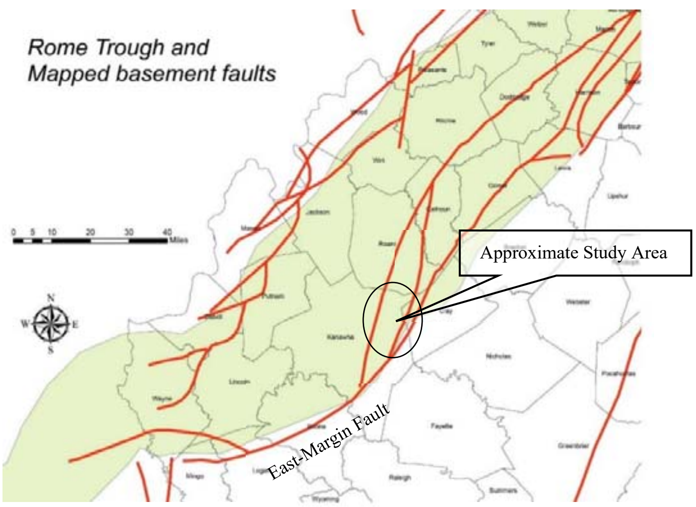


Figure 5: General view of the Rome Trough (Green) and basement faults (Red) through southwestern West Virginia. Adapted from (Dinterman, 2017).

The Warfield Anticline through southern West Virginia is one of the most prominent folds in the area (Coolen, 2003). The Warfield Anticline, depicted in Figure 6, extends approximately 80 miles in a general northeast direction and can be seen in the Silurian Formations and up through Pennsylvanian Formations (Coolen, 2003). Based on the map in Figure 6, the Warfield Anticline ends within the northeast portion of Kanawha County just in the southern edge of the Clendenin Field.

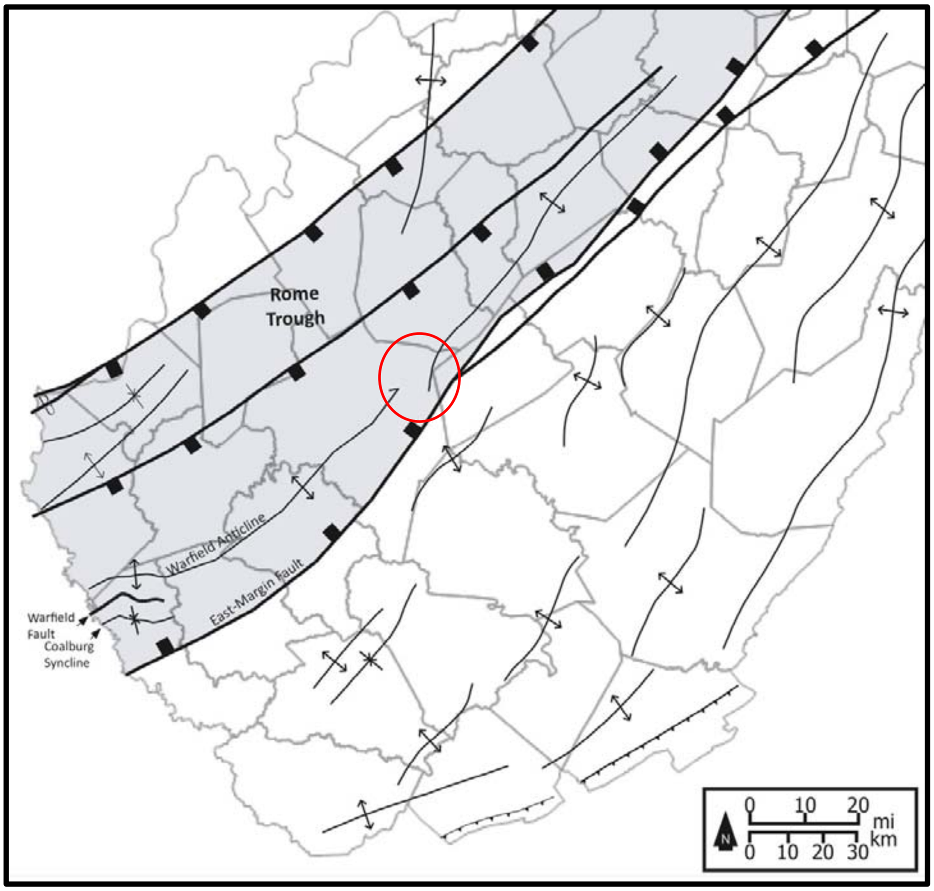


Figure 6: General depicting the Warfield Anticline, Rome Trough, and East-Margin Fault. Approximate Study area outlined in red. (Thomas, 1991; Shumaker, 1993; Gao et al., 2000; Coolen, 2003).

Stratigraphy

Deposition of Devonian-age sediments within the Appalachian can be accredited to the cyclic repetitive deposition of three rock types (Roen, 1983). The rock types that were deposited consisted of clastic sedimentary rocks, organic-rich black shales, and marine carbonate rocks. The typical pattern of deposition in these types of environments consist of the deposition of a basal black shale which is then overlain by clastics, followed by the deposition of carbonates (Roen, 1983). The clastic sedimentary rock intervals coarsen to the east with proximity to the eastern shoreline.

The Upper Devonian Ohio Shale is comprised of the Cleveland Member, Chagrin Member, and the Huron Member. The Cleveland Member is comprised of black shales underlain by the Chagrin Shale Member which is described as a less organic-rich greenish-gray shale (Boswell et. al., 2018;Roen, 1983). These two members could not be distinguished in the geophysical logs, therefore, they are referred to as the Upper Devonian Undifferentiated (UDU). The Huron Member is further subdivided into the Lower, Middle, and Upper Huron (Boswell, 2018). The Lower Huron was the only member encountered throughout the study area. The Lower Huron is the shallowest member of the middle to late Devonian beds within the study area that has been targeted for production.

Underlying the Ohio Shale Formation throughout the study area is the Java Formation. This Formation is comprised of the Hanover Shale Member and the Pipe Creek Member. The Hanover Member is a generally organic-poor shale. Underlying the Hanover Shale is the Pipe Creek Shale. The Pipe Creek Shale is a very thin (<10’) organic-rich shale that can be found throughout the study area (Boswell et. al., 2018). The Pipe Creek, although thin in nature, is a very distinguishable member due to its high gamma ray and low bulk density response on geophysical logs. The Pipe Creek Member is included in many of the completion intervals throughout the field, but is not targeted for production due to its thin nature.

The West Falls Formation underlies the Java throughout the study area. The West Falls Formation is comprised of the Angola Shale Member and the Rhinestreet Shale Member. The Angola Shale consists of shales that are typically organic-poor and underlain by the organic-rich black shales of the Rhinestreet (Boswell, et. al., 2018). The Rhinestreet is another member that is targeted for production throughout the Clendenin Field.

The Sonyea Formation underlies the West Falls Formation throughout the study area. The Sonyea Formation consists of the Cashaqua Shale Member and the Middlesex Shale Member. The Cashaqua like the previous upper members, is an organic-poor gray shale which is underlain by the organic-rich black shales of the Middlesex Member (Boswell, et. al., 2018).

The Genesee Formation underlies the Sonyea throughout the study area. The members of the Genesee include the West River Shale Member which is underlain by the Geneseo Shale Member. The West River Member is a less radioactive gray shale (Boswell, et. al., 2018). The lower Geneseo Shale Member like the previous basal members is an organic-rich black shale. This formation was relatively thin throughout the study area with thickness reported as about 20 to 70 feet. Like many of the other formations thickens to the north and northeast and thins to the west. This formation is also referred to as the Harrell Shale with the lower Geneseo Member called the Burket Shale in its eastern margin outcrop (Boswell, et. al., 2018). For this assessment the units will be referred to as the Genesee Formation, West River Shale, and Geneseo Shale.

The deepest formation of interest within the study area is the Marcellus Shale which is part of the Hamilton Group. The Marcellus, however, is the only member present throughout southern West Virginia (Neal, 1979). While sections of the Marcellus have been found to thicknesses of up to 1,000 feet in more northern states it is relatively thin throughout the Clendenin Field with thicknesses ranging from about 20 to 70 feet (de Witt et. al., 1993). The Marcellus is an organic-rich black shale that is highly targeted throughout the region for its high production of gas. The Marcellus is easily identified in geophysical logs due to its distinctive high gamma signature. The Marcellus is underlain by the Onondaga Limestone. The Onondaga Limestone was partially penetrated by some wells throughout the study area with very few fully penetrating the entire formation.

Many of the Middle Devonian units experienced a suspension of deposition throughout southwestern West Virginia. This suspension of deposition was a result of sea level dropping during the middle Givetian which was potentially triggered by the subsidence after the collision of the Avalon Terrace and the New York promontory (Ettensohn, 1985). This unconformity may have resulted in the thinner beds we encounter in the Middle Devonian.

CHAPTER III: METHODS

Geophysical Well Log and Interpretation

Geophysical logs for the wells within the study area (Clendenin Well Field) were obtained through The West Virginia Geological and Economic Survey (WVGES) online database. Of the approximately 696 wells throughout the Clendenin field only 133 wells contained scanned geophysical logs. Only 32 of the logs penetrate the subsurface to depths great enough to include the Marcellus Shale. Due to the lack of wells in certain portions of the study area, particularly the north and northwest, wells penetrating the Marcellus Shale in neighboring fields were used to fill in gaps throughout the study area. Geophysical logs allow us to identify various strata based on the measured properties within the strata without collecting a physical core. The logs are capable of measuring properties such as temperature, pore fluid pressure, porosity, density, electrical resistivity, and gamma radiation content. For the purpose of this assessment we utilized gamma-ray and resistivity logs.

Stratigraphic formations contain natural radiation that can vary depending on the mineral make-up of the formation. Different strata emit this natural radiation at differing rates which makes possible correlating the types of materials by their gamma-ray signatures. For instance, fine-grained (clays and silts) strata such as shales tend to contain more radioactive minerals, such as potassium, than coarse grained sandstones. Therefore, the gamma-ray signatures in these fine-grained formations material will be higher than those of the coarse-grained strata. Additionally, carbonates also tend to emit a lower gamma signature than the fine-grained strata (Dresser Atlas, 1982).

Sediments making up these the formation are typically low conductors of electrical current. Since the formation rock itself is typically a low conductor (Dresser Atlas, 1982), the differences separating the formations from one another can be caused by differences in porosity, formation water, and hydrocarbon content. Typically, sandy or coarse-grained formations (sandstones) have the ability to hold more water than its fine-grained counterpart (shales or mudstones), therefore, the resistivity in these formations are lower. Also, hydrocarbon containing formations may reflect higher resistivity to electrical current due to the hydrocarbons low conducting abilities.

Well records obtained from WVGES provide all recorded historical development details along with production data from the time of installation to present. The wells used for this assessment are identified by an API number which was standardized by the American Petroleum Institute (API). The API numbers identify the well by state drilled in, county drilled in, and permit number for the well. An example of the well identification number along with examples of the types of geophysical logs used in this assessment is provided as Figures 7 and 8.

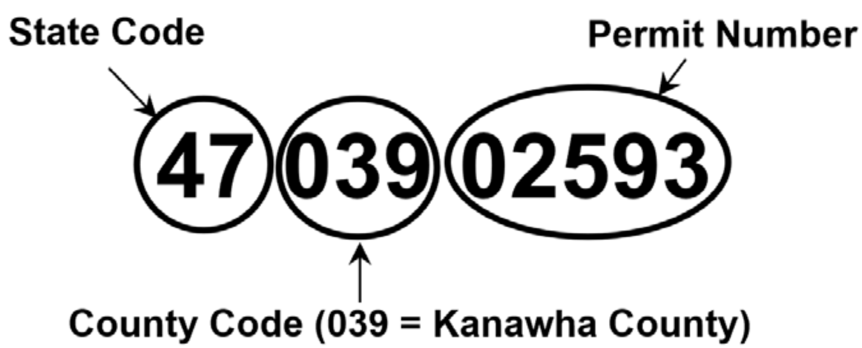


Figure 7: Example of API Well Identification Number.

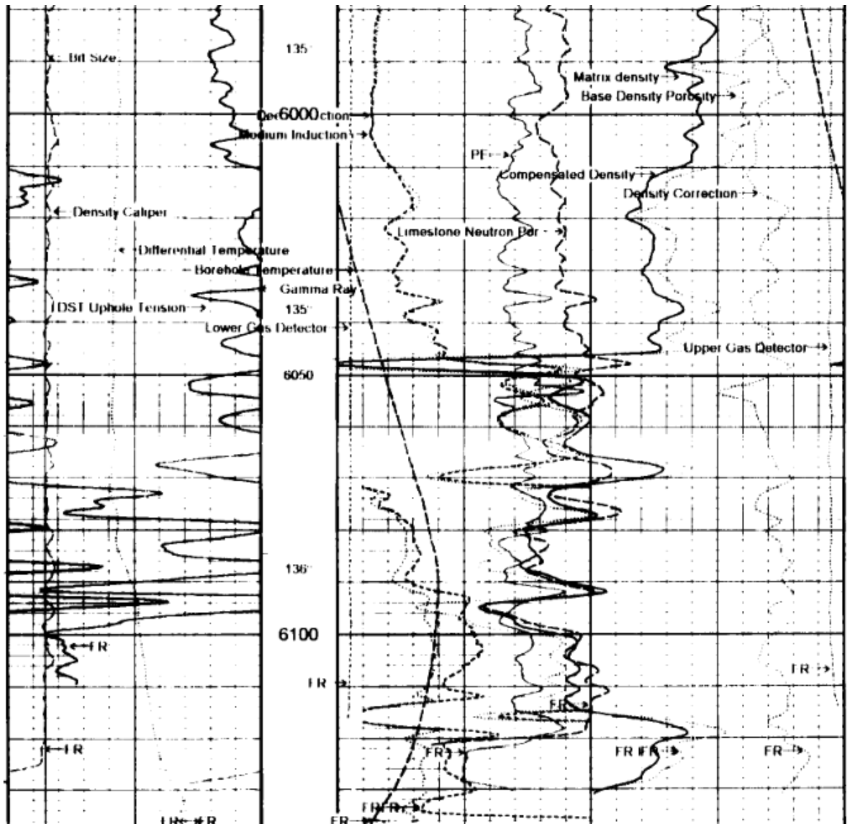


Figure 8: Example of typical geophysical log. Adapted from WVGES Pipeline database.

Stratigraphic Cross-Section Production

After compiling the available well logs within the study area, several logs throughout the Clendenin Field were selected to produce stratigraphic cross-sections. The logs selected were chosen based on the available logs and the deepest formation penetrated (Marcellus or Onondaga). Other considerations for selecting the wells was the clarity of the logs. Due to the age of the logs and scanning equipment from the time the logs were scanned, some logs were not easily read. Using a combination of Microsoft PowerPoint and Adobe Pro, two stratigraphic cross-sections were produced transecting the Clendenin Field. One stratigraphic section transected the field from north to south and the other west to east in an attempt to capture a 2-D view in both directions to help determine constraints on deposition, potential deformation, and other potential controls on the stratigraphy through the field.

The stratigraphic cross sections were hung on the base of the Sunbury Shale and correlated based on the gamma and resistivity signatures of the formations. The base of the cross sections ended in the Onondaga Limestone where they only capture the upper few feet of the Onondaga Limestone. The cross sections were scaled vertically, however, due to constraints on available software the horizontal distance between the wells is not to scale. This may have a small effect on how the stratigraphy appears in the cross section but is considered when interpreting them. Although gamma and resistivity logs were used to interpret the formations and members depth, only the gamma log portion is depicted in the stratigraphic cross-sections to reduce clutter and make them more readable.

Isopach and Structure Contour Map Production

Isopach maps were created to help interpret the thickening and thinning trends of the formations and their members across the field. Structure contour maps were also created to help visualize the strike and dip or general trend of the top of the formations and their members throughout the study area. These maps were created from raw data obtained from the well logs in conjunction with the inferred depth to top and bottom of the formations. These inferences were made based on the aforementioned gamma and resistivity logs. The data obtained consisted of longitude, latitude, and calculated thickness from the log interpretations. Upon collecting and compiling this data for each formation and member of interest for each selected well a spreadsheet was created using Microsoft Excel which was then converted to a text file for input in ArcMap to interpret. Using ArcMap, the data was converted into vector point data using the latitude and longitude as the “X, Y” values and the “Z” value was the thickness of the formations and members for the isopach maps. The “Z” value for the structure contour maps represented the depth below mean seal level (MSL) to the top of the formations and members.

Several options were explored for interpreting the isopach contours and structure contours based on the data collected from the geophysical logs throughout the field. Based on the results and the method used in the statistical interpolation, it was determined that natural neighbor was the better option for the purpose of this study for creating interpreting the contours. Natural neighbor interpolation techniques utilize the nearest known data point to the area to be inferred and applies a weighting to the point based on proportionate areas (Sibson, 1981).

Well Production Analysis Methods

Production data were collected from the WVGES "Pipeline Plus" data base for each well within the Clendenin Field. The database contains information regarding the completion interval for the well, the type of completion method (open hole or fracturing), type of well (vertical or horizontal), pay type, production per month and total annual production for years since initial production began. Although the wells were developed and completed at different times to maintain uniformity only the first 12 months of production was used for comparison. Production data for wells from the years prior to 1980 and years 1985, 1987, and 2000 were not used as part of this study based on the incomplete reporting for those years per (Avary, personal communication, March 20, 2019). The types of wells (vertical or horizontal) and completion methods were also noted to better understand the amount of production from the different well types and better compare the wells. It is important to note the types of wells because a horizontal well may have the potential to produce more than a vertical well that is within the same formation and same thickness of formation material. This can be caused by the potential for horizontal wells to intersect more fractured zones that contain gas and/or oil depending on the length of the screened area.

CHAPTER IV: RESULTS

Cross Sections

Cross section A-A' is comprised of seven (7) geophysical logs for the wells transecting the Clendenin Field from west to east. Cross section B-B' is comprised of five (5) geophysical well logs transecting the field from north to south. A map depicting the general location and orientations of the cross-sections in plan view is provided in Figure 9 below. Of the eleven wells used to produce the cross-sections, only six penetrate the Marcellus and capture the upper Onondaga Limestone. For this study the Marcellus was the deepest formation of interest, therefore, wells penetrating into and completely through the Marcellus were targeted. Wells that were not advanced deep enough to reach the Marcellus were utilized, from a production standpoint, to correlate the differences in amount of production from non-Marcellus wells to Marcellus containing wells.

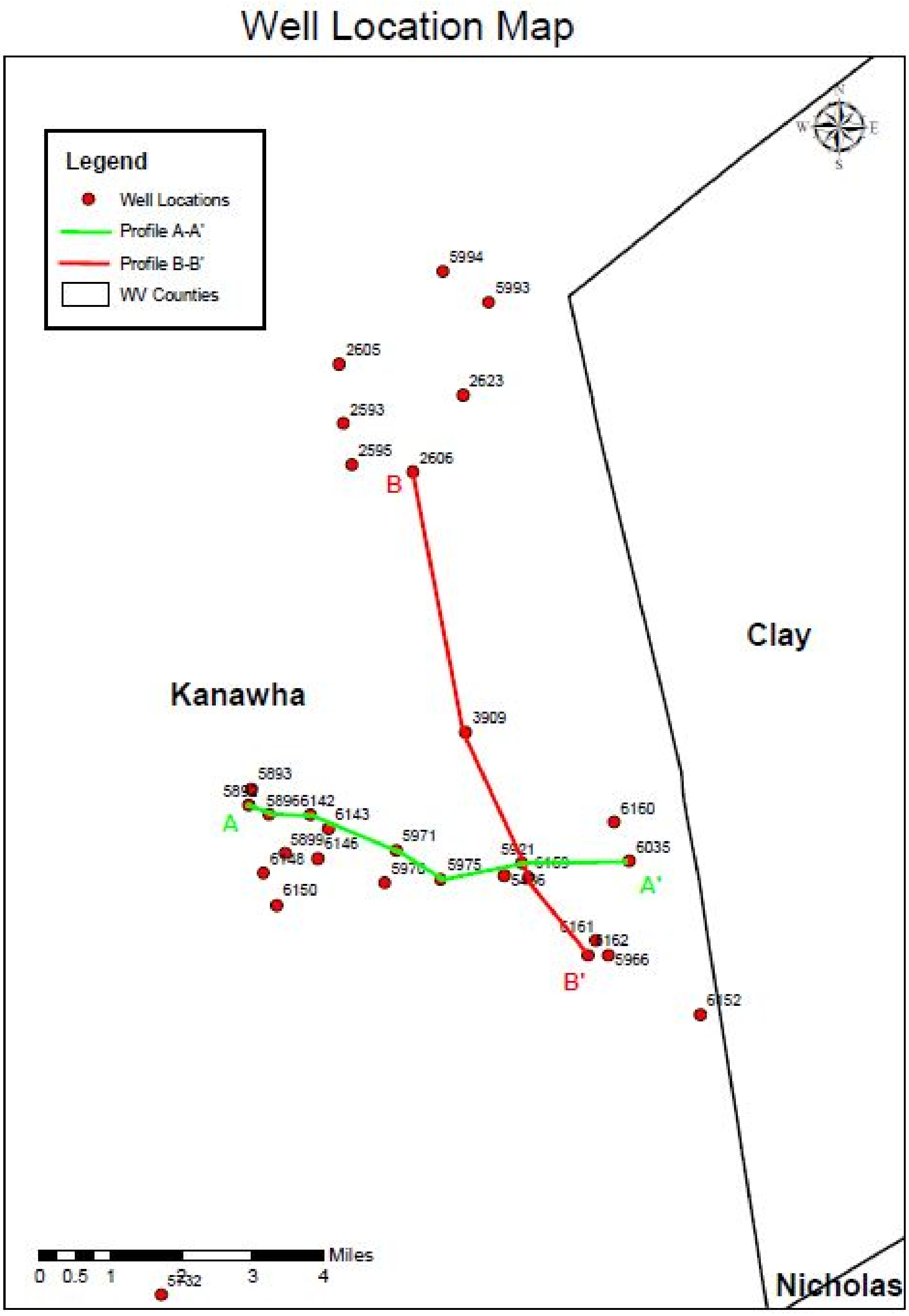


Figure 9: Well Location Map with cross sections orientation depicted in planview.

Cross Section A-A'

Beginning at the base of the Sunbury Shale, cross-section A-A' (Figure 10) depicts the Ohio Shale/Upper Devonian Undifferentiated (UDU) extending to depths ranging from approximately 4,046 to 4,544 feet below the ground surface and ranging in thickness from 2,018 to 2,052 feet. This formation gradually thins in the westerly direction with the thickest portions occurring in the eastern portion of the study area. This formation is comprised of equivalents of the Cleveland Shale, Chagrin Shale, and Huron Shale. A table summarizing the subsea elevations and thickness of the Ohio Shale at each well location is provided in Appendix A.

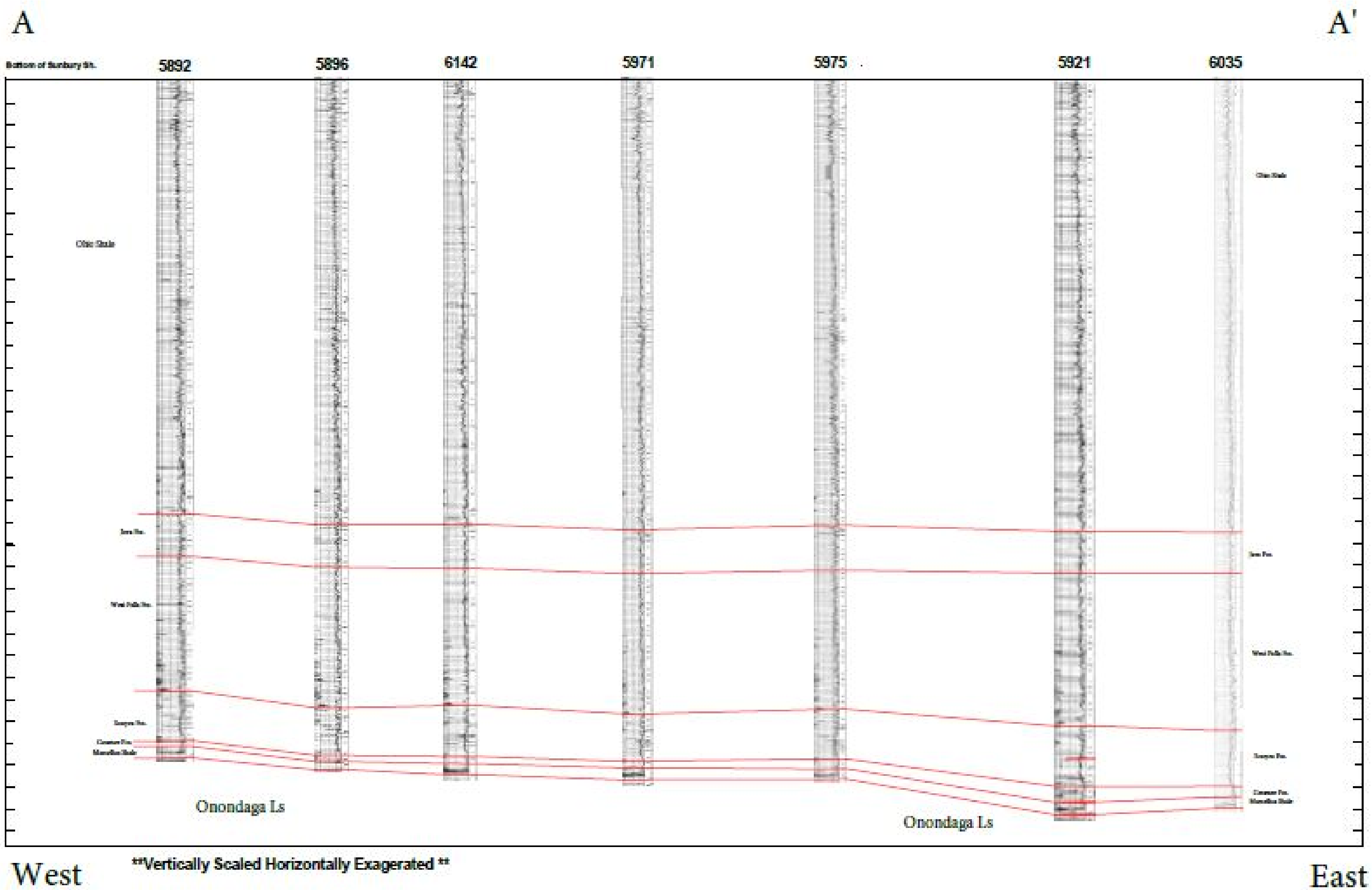


Figure 10: Cross Section A-A’ shown as looking generally north. Geophysical logs adapted from WVGES.

Underlying the UDU in the profile, the geophysical logs depicted the Java Formation to depths ranging from 4,244 to 4,740 feet below the ground surface. Thickness of this formation across the site ranges from 190 to 238 feet. The formation generally thins in the westerly direction with a difference of 48 feet between the thickest and thinnest section. This formation is comprised of the Hanover Shale and the Pipe Creek Shale members. The Hanover Shale makes up a majority, more the $3/4^{th}$'s, of the Java Formation with the Pipe Creek Shale only making up a small portion due to its thin nature. A table summarizing the subsea elevations and thickness of the Java Formation at each well location is provided in Appendix A.

Underlying the Java Formation in the cross-section is the West Falls Formation. This formation was detected in the geophysical logs to depths ranging from 4,876 to 5,400 feet below the ground surface. Thickness of this formation across the site ranges from 610 to 712 feet and generally thins in the westerly direction. This formation is comprised of the Angola Shale Member which makes up the top half of the formation and the Rhinestreet Shale Member which makes up the lower portion. A table summarizing the subsea elevations and thickness of the West Falls Formation and its members at each well location is provided in Appendix A.

Underlying the West Falls Formation in the cross section is the Sonyea Formation. This formation was detected in the geophysical logs to depths ranging from 5,092 to 5,654 feet below the ground surface. Thickness of this formation across the site ranges from 216 to 272 feet and generally thins in the westerly direction. This formation is comprised of the Cashaqua Shale Member in the upper quarter of the formation. The Middlesex Shale Member makes up the lower portion of the formation. A table summarizing the subsea elevations and thickness of the Sonyea Formation and its members at each well location is provided in Appendix A.

Underlying the Sonyea Formation in the cross section is the Genesee Formation. This formation was detected to depths ranging from 5,122 to 5720 feet below the ground surface in the remaining logs. Thickness of this formation across the site ranges from 21 to 72 feet and generally thins in the westerly direction. This formation is comprised of the West River Shale Member and the Geneseo Shale Member. A table summarizing the subsea elevations and thickness of the Genesee Formation and its members at each well location is provided in Appendix A.

Underlying the Genesee Formation in the cross-section is the Marcellus Shale. The Marcellus Shale was detected in the geophysical logs to depths ranging from 5,176 to 5,778 feet below the ground surface. Thickness of this formation across the site ranges from 27 to 58 feet and generally thins in the westerly direction. In well 4703905892, the furthest west well in the stratigraphic section, the Marcellus increases to a thickness of 51 feet. Other wells within the vicinity of this well also show a slightly thickened section of the Marcellus and wells further west continue a general thinning trend. The Marcellus Shale is the deepest formation fully penetrated by the wells used to create this cross-section. The Onondaga Limestone is partially penetrated throughout the field with only a few wells fully penetrating the full thickness of the Onondaga.

Cross Section B-B'

Beginning at the base of the Sunbury Shale, which ranges in depth in the cross section from 2,432 to 2,646, cross-section B-B' (Figure 11) depicts the Ohio Shale/UDU extending to depths ranging from approximately 4,490 to 4,700 feet below the ground surface and ranging in thickness from 2,044 to 2,098 feet. This formation gradually thins to the north with the thickest portions occurring in the southern portion of the study area.

Underlying the UDU in the profile, the geophysical logs depicted the Java Formation to depths ranging from 4,680 to 4,908 feet below the ground surface. Thickness of this formation across the site ranges from 162 to 226 feet. The formation generally thins in the northerly direction across the field.

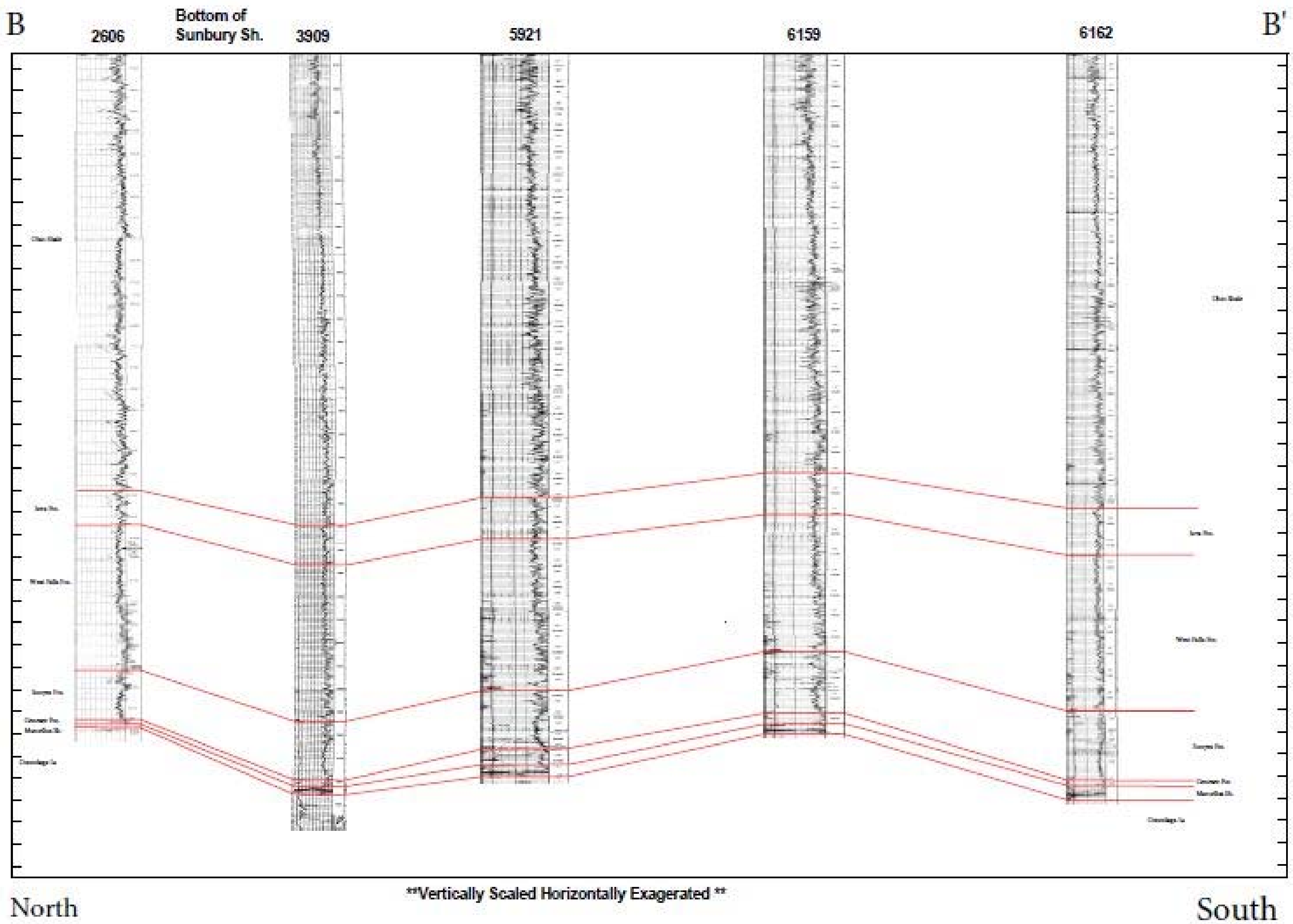


Figure 11: Cross Section B-B' shown as looking generally east. Geophysical logs adapted from WVGES.

Underlying the Java Formation in the profile B-B' the West Falls Formation is depicted as ranging from 5,376 to 5,578 feet below the ground surface. Thickness of this formation across the profile ranges from 670 to 716 feet and generally thins to the north. The thinnest portion of the profile is depicted in well number 4703906159 which is surrounded to the south by the thickest section detected in the profile in well number 4703906162 and the second thickest section to the north in well number 4703905921.

Underlying the West Falls Formation in the profile is the Sonyea Formation. This formation is depicted as ranging from 5,648 to 5,878 feet below the ground surface. Thickness of this formation across the profile ranges from 236 to 312 feet and generally thins to the north.

Underlying the Sonyea Formation in the cross-section is the Genesee Formation. This formation is depicted as ranging from 5,720 to 5,946 feet below the ground surface. Thickness of this formation across the site ranges from 17 to 72 feet. The Genesee is depicted as being the thickest in the vicinity of well number 4703905921 with the second thickest portion detected in well number 4703906159 at 68 feet. The formation thins to the north and south of these wells and generally thins in the westerly direction.

Underlying the Genesee Formation in the cross-section is the Marcellus Shale. The Marcellus Shale was detected in the geophysical logs to depths ranging from 5,778 to 5,981 feet below the ground surface. Thickness of this formation across the site ranges from 22 to 65 feet and generally thins to the north.

The profiles together depict a west-northwest thinning trend throughout the Clendenin Field. Both profiles also depict several "lows" and "highs" within the eastern and southern portion of the fields. These areas are described in the following discussion of the isopach maps and are further discussed within that section.

Isopach Maps

Isopach maps were created for each formation within the studied area. The isopach maps depict the variation of thickness and the thickening/thinning trend across the field. Several wells outside of the study area were used to prevent an edge effect from creating a skewed thickness contour. The isopach maps also help with correlating and understanding the controls on formation.

The Ohio Shale/UDU isopach map (Figure 12) depicts the interval having an overall thinning trend to the west as depicted in the stratigraphic cross-section A-A'. Thickness of the Ohio Shale within the Clendenin field falls within the 2,000' to 2,250' isocontour. Several of the easternmost wells fall on the edge or within the 2,250' to 2,500' isocontour.

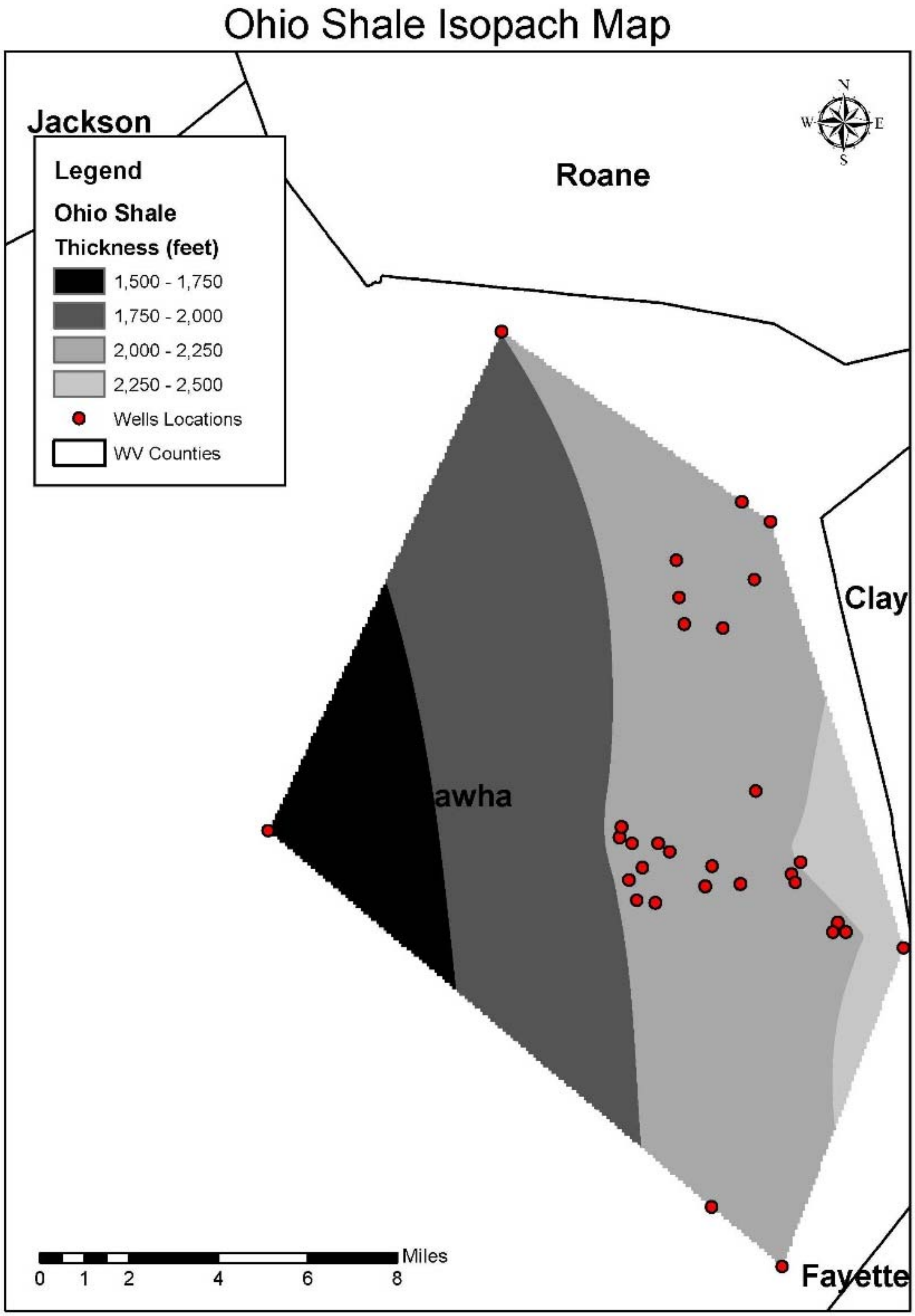


Figure 12: Ohio Shale Isopach Map.

The Java Formation isopach map (Figure 13) depicts a thinning trend generally to the northeast across the field. A small isolated area of thinning where thickness ranges from approximately 100 to 150 feet is located within the southeast of the field in the vicinity of well number 4703905159. The majority of the field ranges from 150 to 200 feet in thickness.

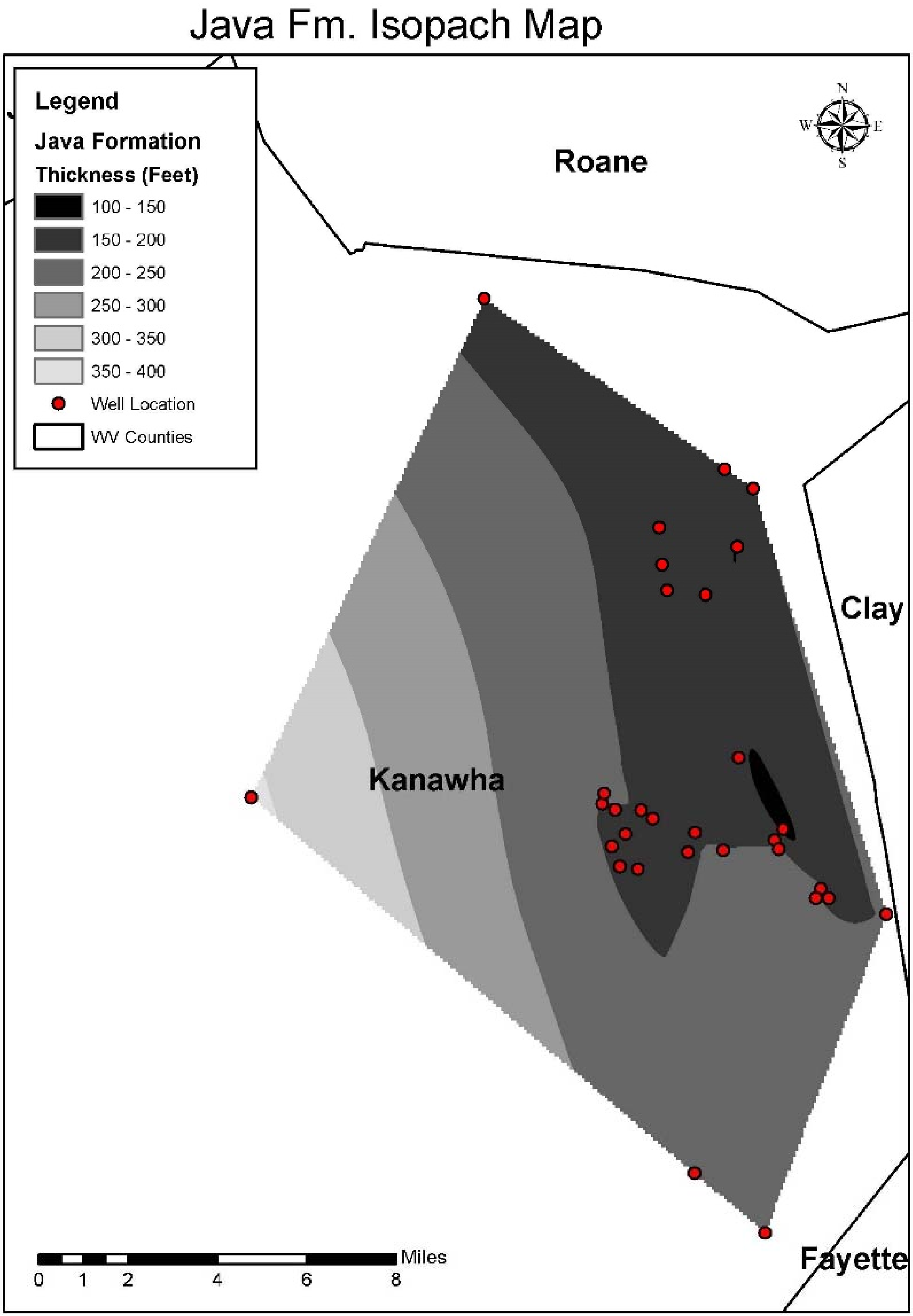


Figure 13: Java Formation
Isopach Map.

The West Falls Formation isopach map (Figure 14) depicts the formation thickening to the east and west and thinning to the north and south. The majority of the wells in the Clendenin Field are in the range of 600 to 700 feet thick. Several wells to the east within the field near the border with Clay County fall within the 700 to 900 feet thick range. Isopach maps of the two members of the West Falls Formation, the Angola Shale and Rhinestreet Shale (Figures 15 & 16) show an overall similar thickening and thinning trend. The Angola Shale Member generally thins to the north and thickens to the south-southwest. The Angola Shale isopach map also depicts an area of thickening throughout the center of the field. The formations thickest portion (350 to 450 feet) is encountered to the north of the field near well number 4703902623. An isolated area of thinning is depicted to the south east of the field where the formation has a thickness ranging from approximately 150 to 200 feet. The Rhinestreet Shale Member isopach map shows the member thinning to the south and south-southwest. The Rhinestreet also depicts an isolated area of thinning area as in the Angola member, however, this area is located to the northern portion of the field where the thicker portion of the Angola is located.

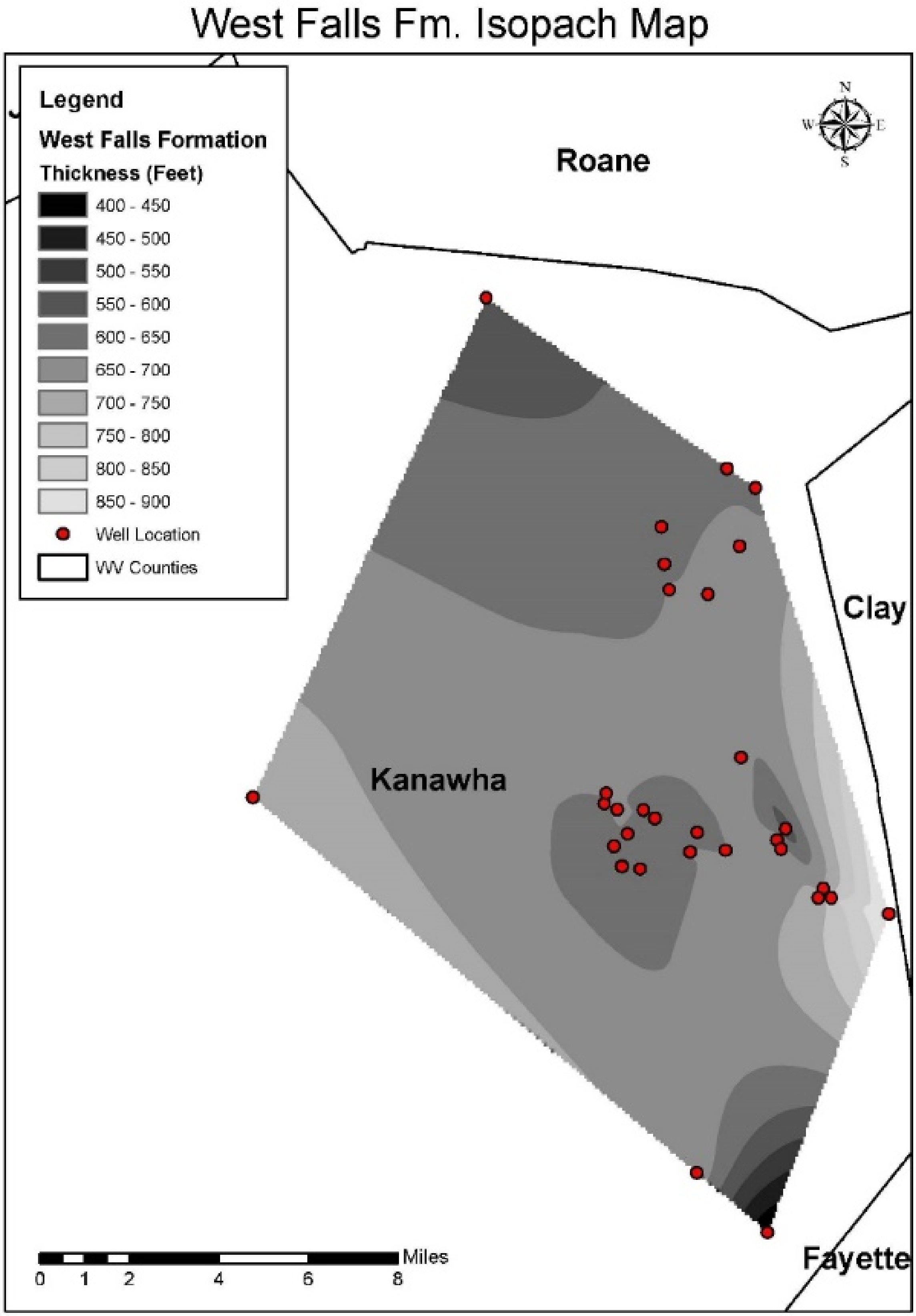


Figure 14: West Falls
Formation Isopach Map.

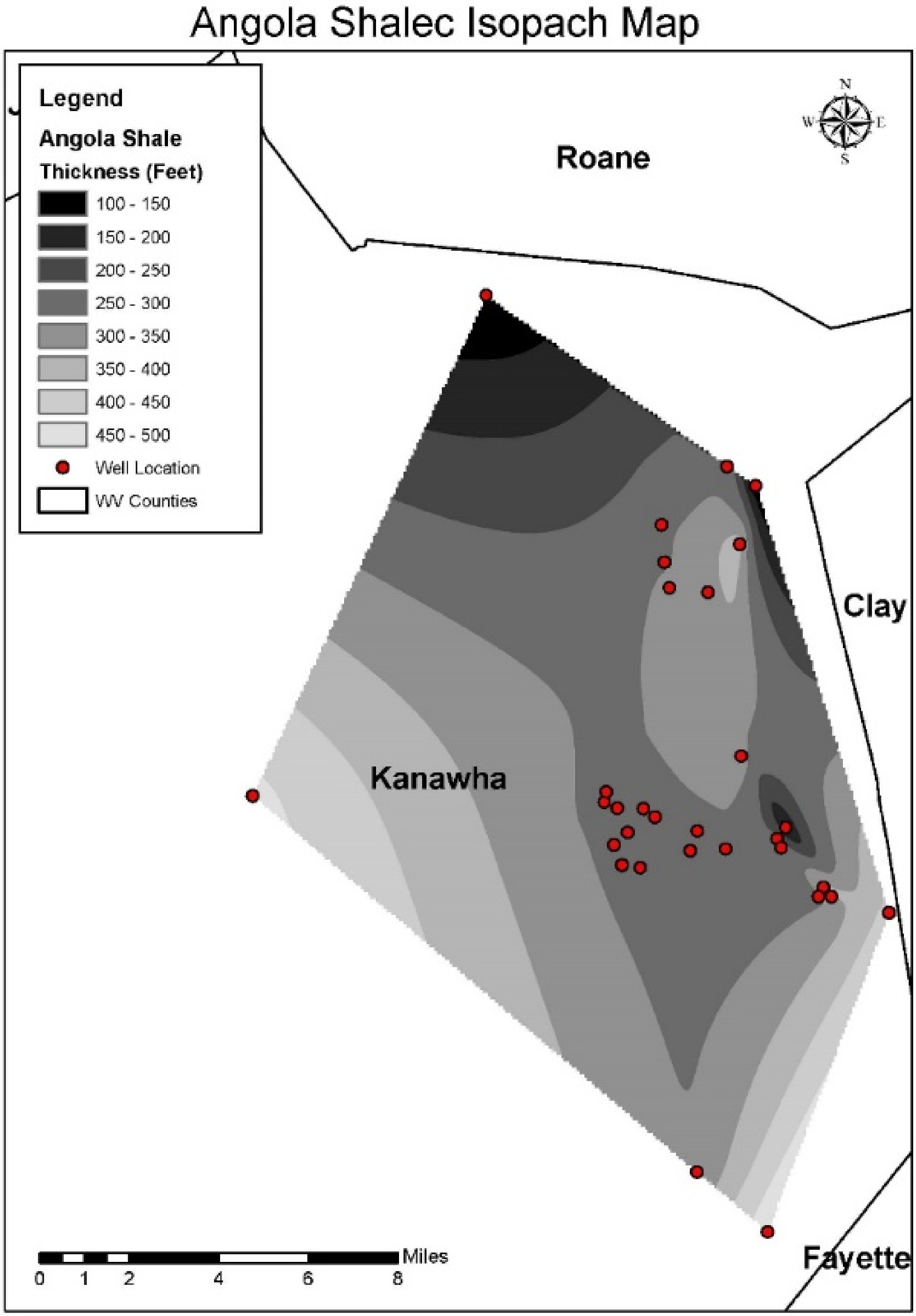


Figure 15: Angola Shale
Isopach Map.

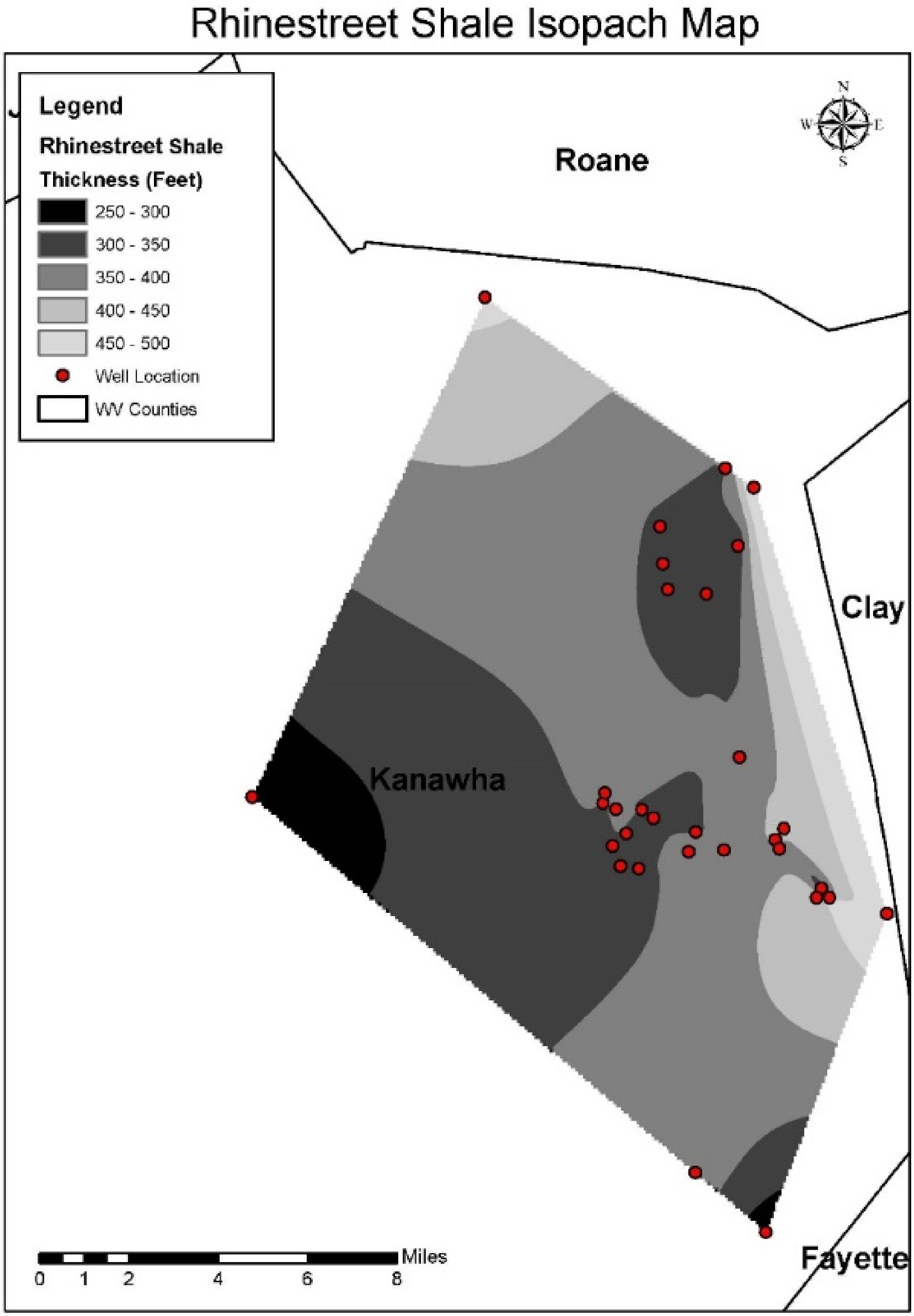


Figure 16: Rhinestreet Shale Isopach Map.

The Sonyea Formation isopach map (Figure 17) depicts the formation as thinning to the northwest and southeast with a majority of the field falling within the 200 to 280 foot thickness range. The Cashaqua Shale Member of the Sonyea Formation shows a similar trend within the Cashaqua Shale isopach map (Figure 18). The Middlesex Shale Member isopach map (Figure 19) depicts a thinning trend generally to the south. The Middlesex Member is at its thickest within the west and central portions of the field with a thickness ranging from 30 to 40 feet. The majority of the Middlesex Shale is relatively thin throughout the field with a thickness ranging from 10 to 20 feet.

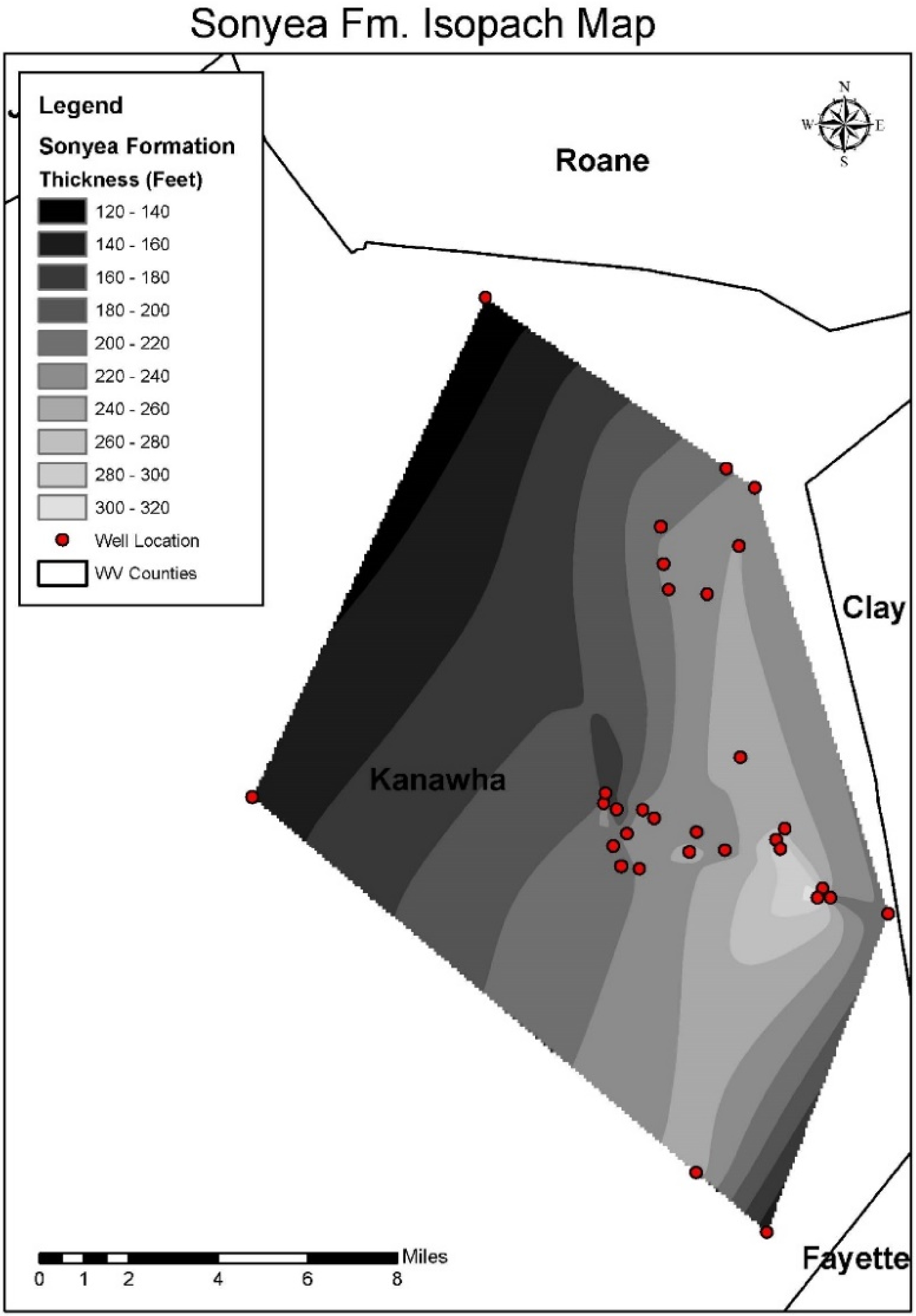


Figure 17: Sonyea Formation
Isopach Map.

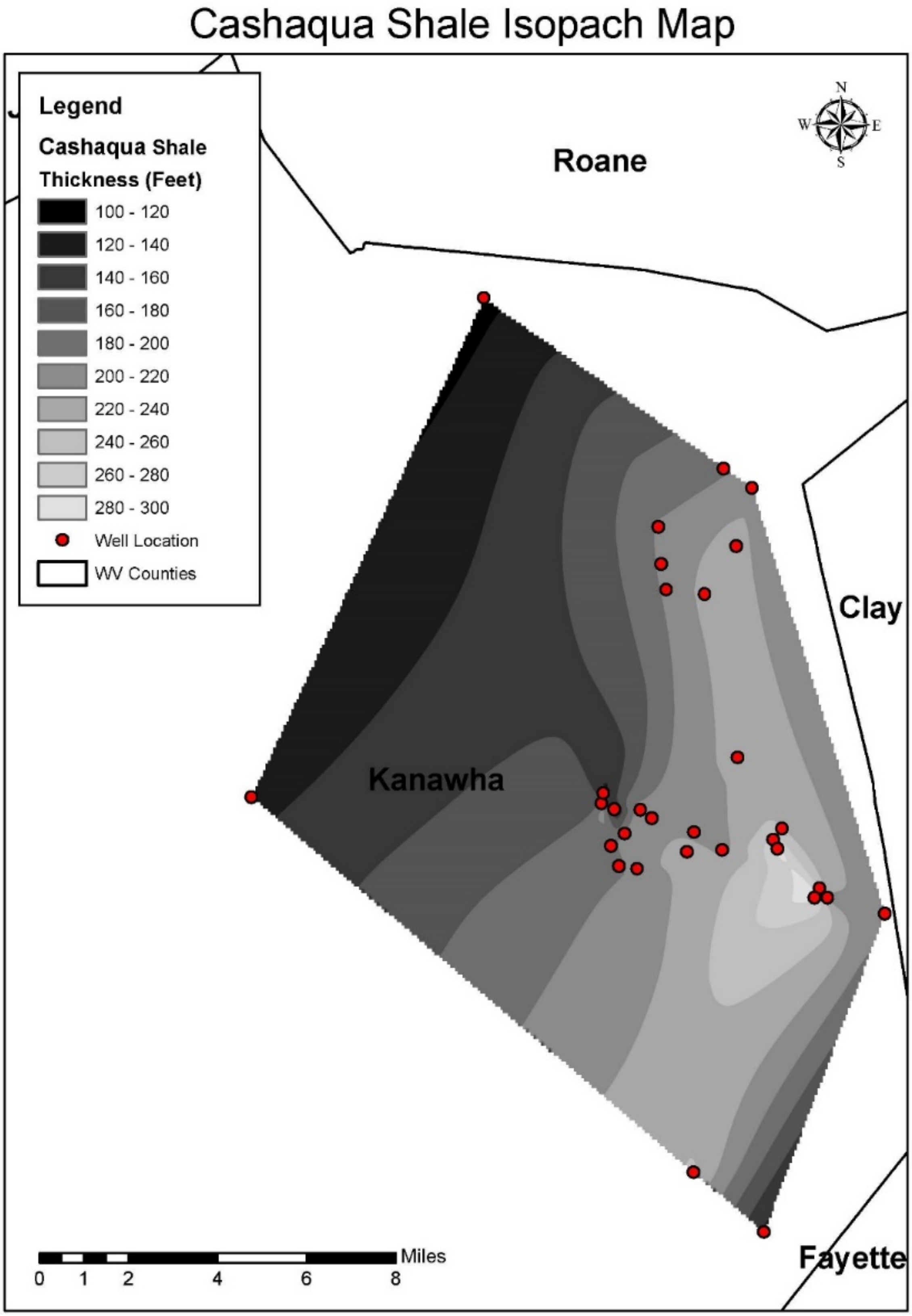


Figure 18: Cashaqua Shale Isopach Map.

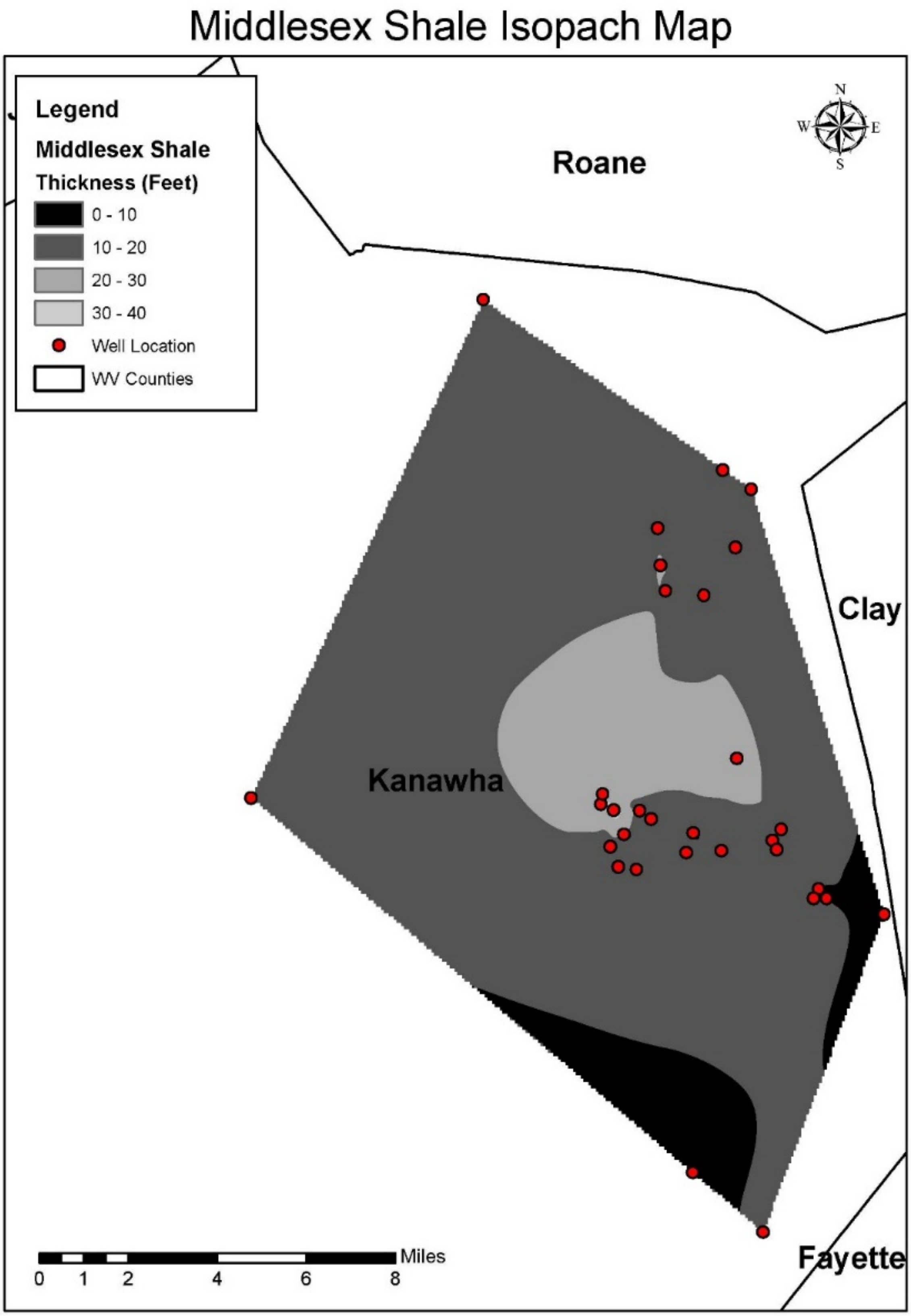


Figure 19: Middlesex Shale
Isopach Map.

The Genesee Formation isopach map (Figure 20) shows a thinning trend generally to the west. An area of thinning is depicted to be present along the center of the field from well number 4703902606 in the north to well number 4703903909 toward the southern end of the field. This area of thinning can also be seen within the B-B' stratigraphic cross-section. The West River Shale Member isopach map (Figure 21) shows the same westward thinning trend with some thickening to the south. The Geneseo Shale Member isopach map (Figure 22) shows an area of thinning around the vicinity of well number 2703903909 with the formation thickening in all direction surrounding that area. A small area of thickening can be seen surrounding well number 4703902606 in the northern portion of the field.

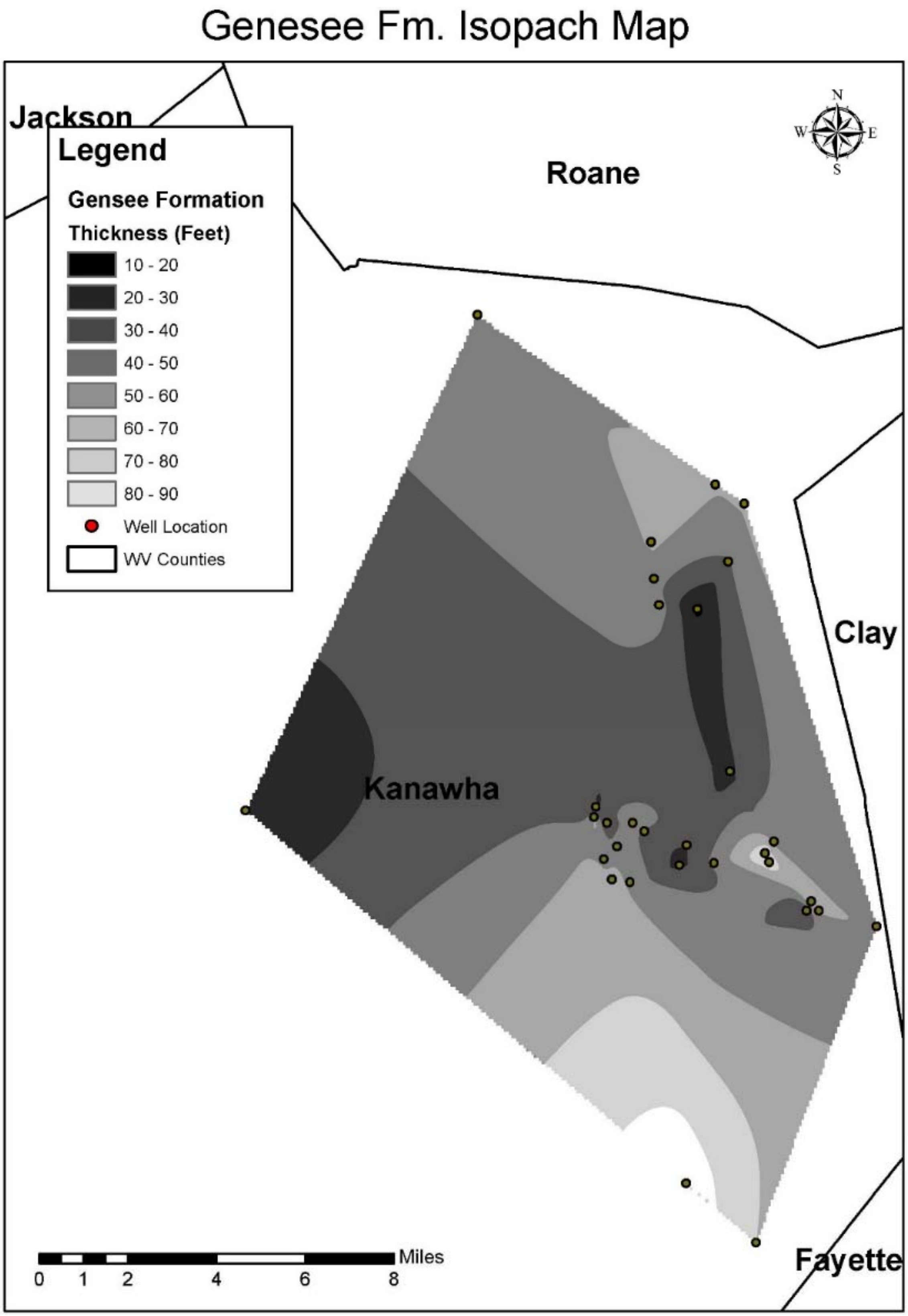


Figure 20: Genesee Formation
Isopach Map.

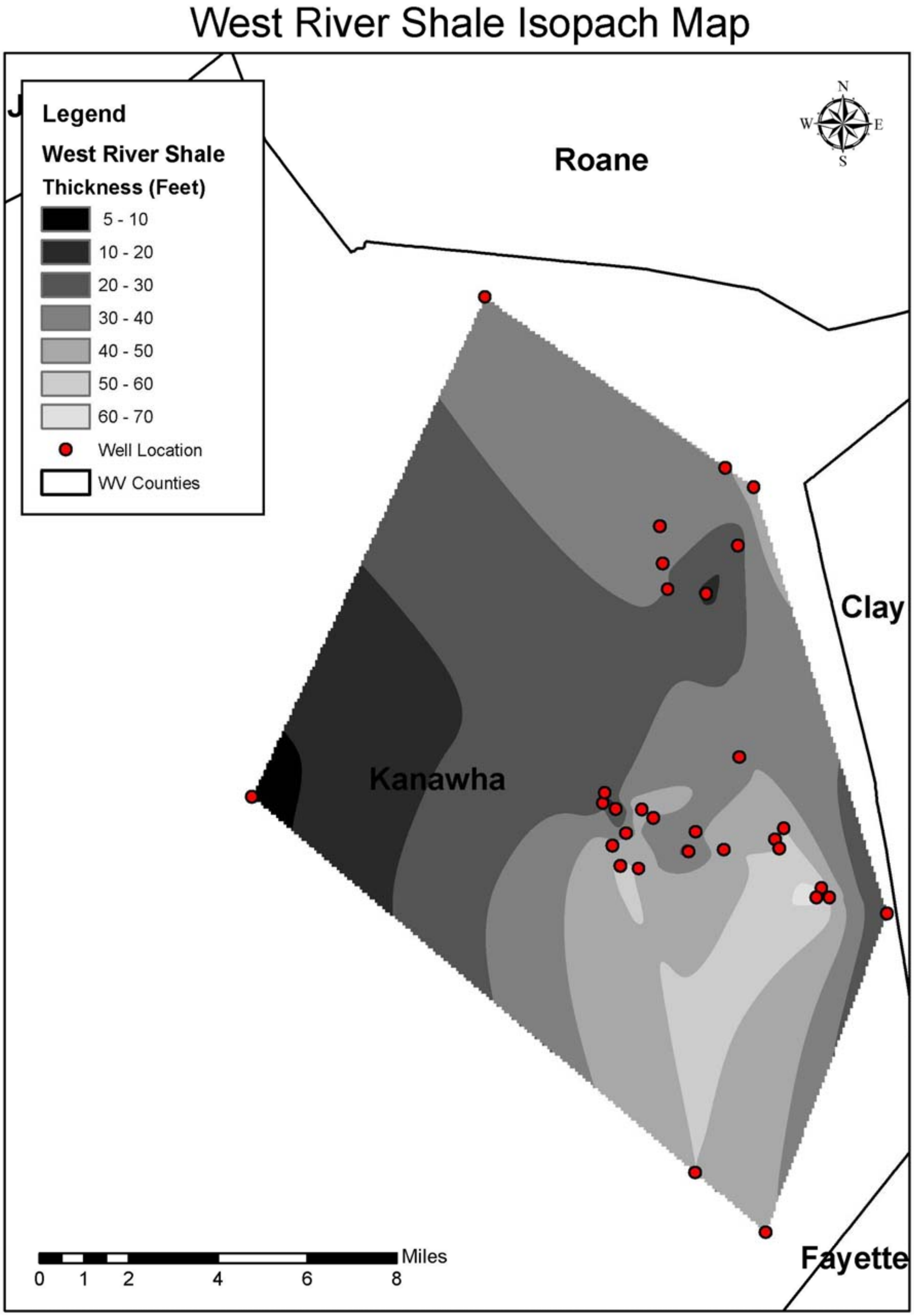


Figure 21: West River Shale
Isopach Map.

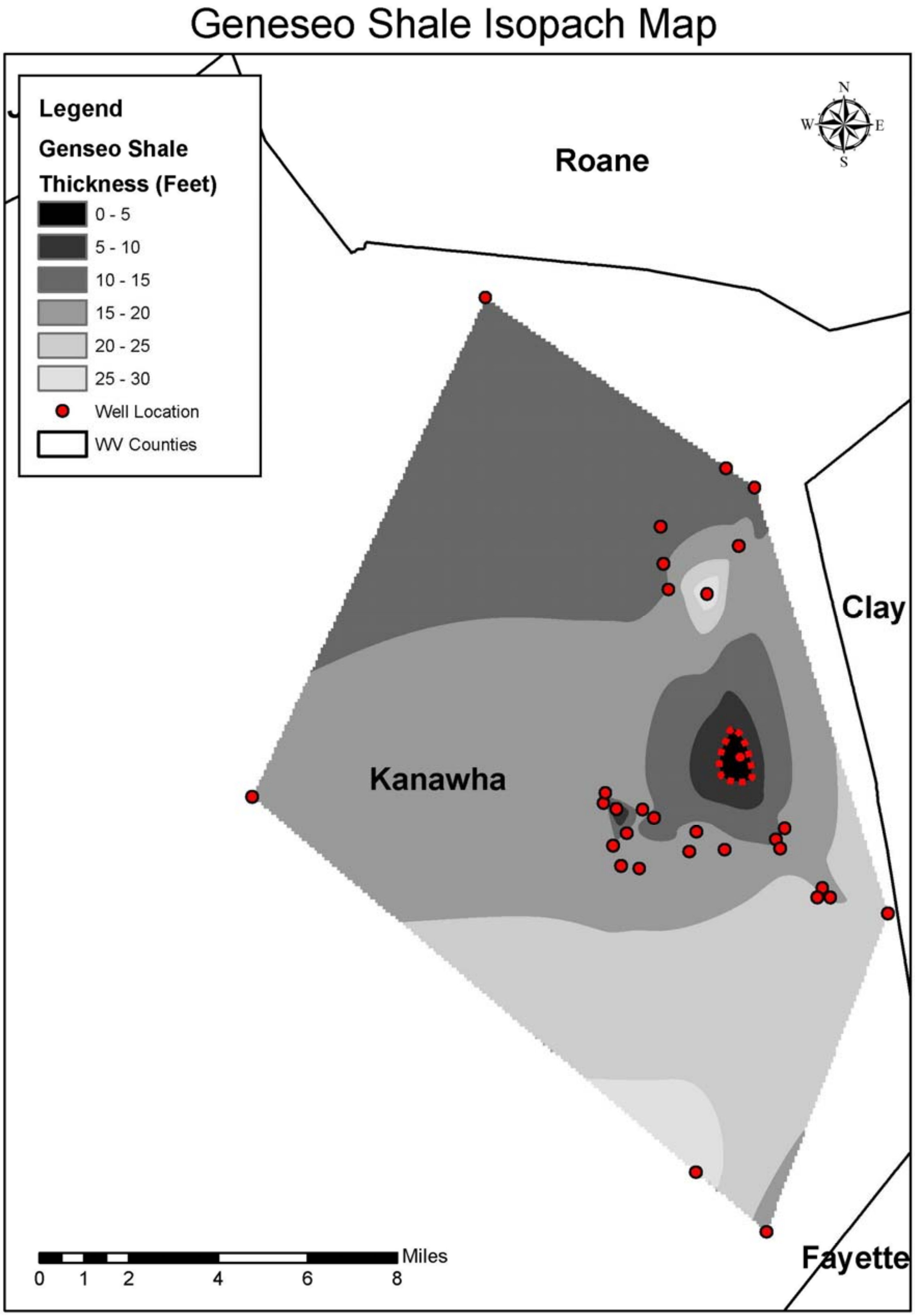


Figure 22: Geneseo Shale Isopach Map.

The Marcellus Shale isopach map (Figure 23) shows a general thinning trend to the south-southwest and west. The majority of the field to the south contains areas of Marcellus ranging from 30 to 60 feet in thickness. This isopach map, like many of the aforementioned maps, contains the same isolated thinning area to the north in the vicinity of well number 4703902606 and thickening in the vicinity of the wells to the southern central portion of the field.

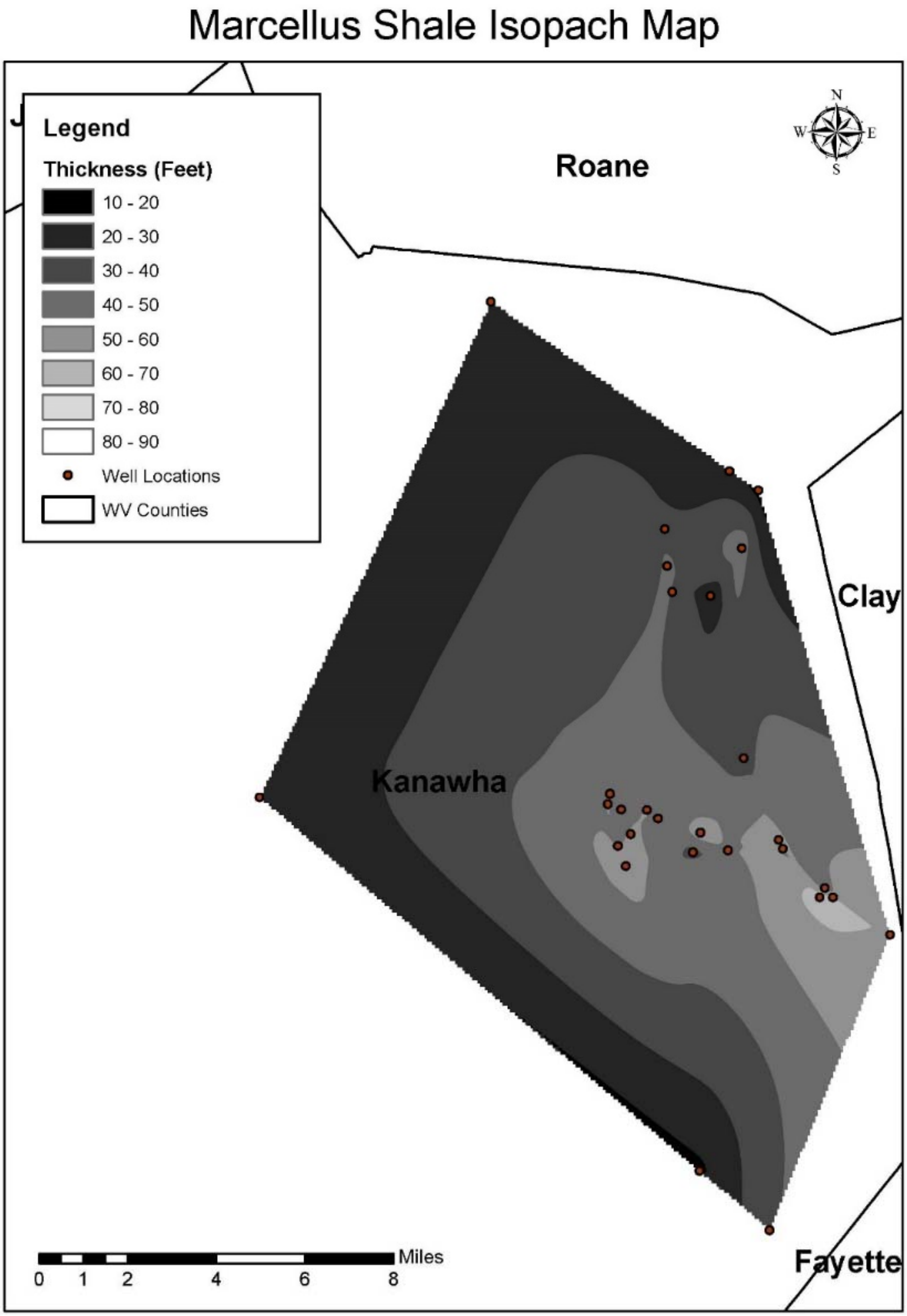


Figure 23: Marcellus Shale
Isopach Map.

Overall the isopach maps in conjunction with the stratigraphic cross-sections depict a generally gentle thinning across the site for each of the formations. All of the formations within the field appeared to contain some isolated areas where the formations contained thicker or thinner intervals. These isolated areas typically occurred along the eastern portion of the field up to the narrowing northern portion of the field. These areas may be strongly influenced by their proximity to the Eastern Fault Margin of the Rome Trough which transects that vicinity along with several smaller unnamed faults that transect the site. A general site overlay map depicting these faults and their location in relation to these areas is provided in Figure 33.

Structure Contour Maps

Structural contour maps showing the depths (below mean sea level) to the tops of formations in the study area were created. The structure contour maps were also utilized to help visualize the structural controls on production and distribution of the formations across the field. Structure contour maps for the West Falls, Sonyea, and Genesee formations were not created since the top of their upper members (Angola, Cashaqua, and West River) are the same surface.

The Ohio Shale structure contour map (Figure 24) depicts the formation generally dipping to the northwest and southeast. A structural high occurred in the vicinity of well number 4703906151 in the southwest portion of the field with the depth to the top below MSL at approximately 947 feet. A second small area to the eastern portion of the field in the vicinity of well number 4703906035 depicts a structural low of approximately 1,600 feet below MSL. The average depth to top of the formation across the field falls within the 1,200 to 1,300 feet below MSL range.

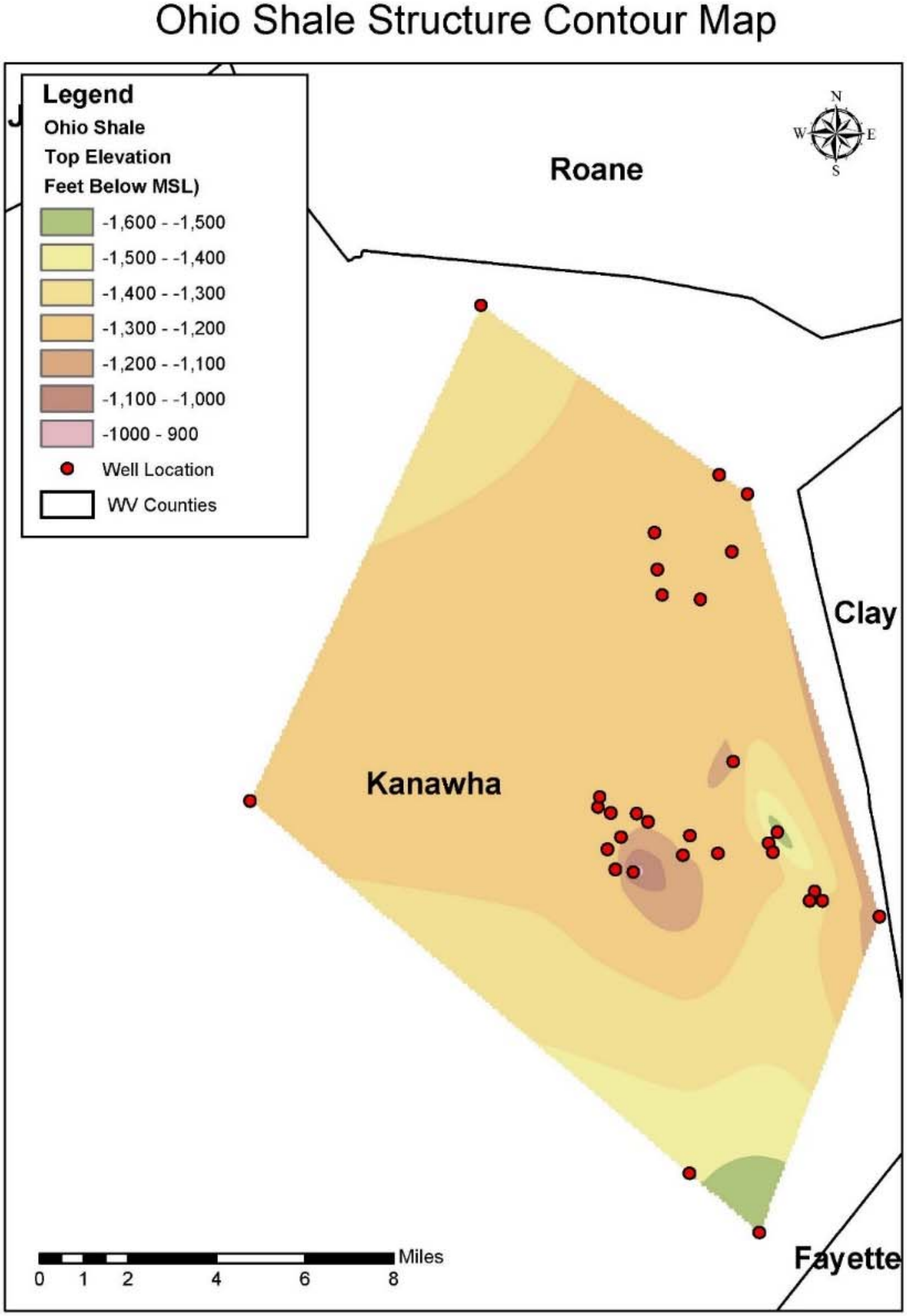


Figure 24: Ohio Shale Structure Contour Map.

The Java Formation/Hanover Shale structure contour map (Figure 25) shows gradual dip to the southeast with the formation becoming shallower westward through the site. The majority of the field lies within the 3,200 to 3,300 foot below MSL range. A small depression is depicted to the north of the field in the vicinity of well number 4703902606.

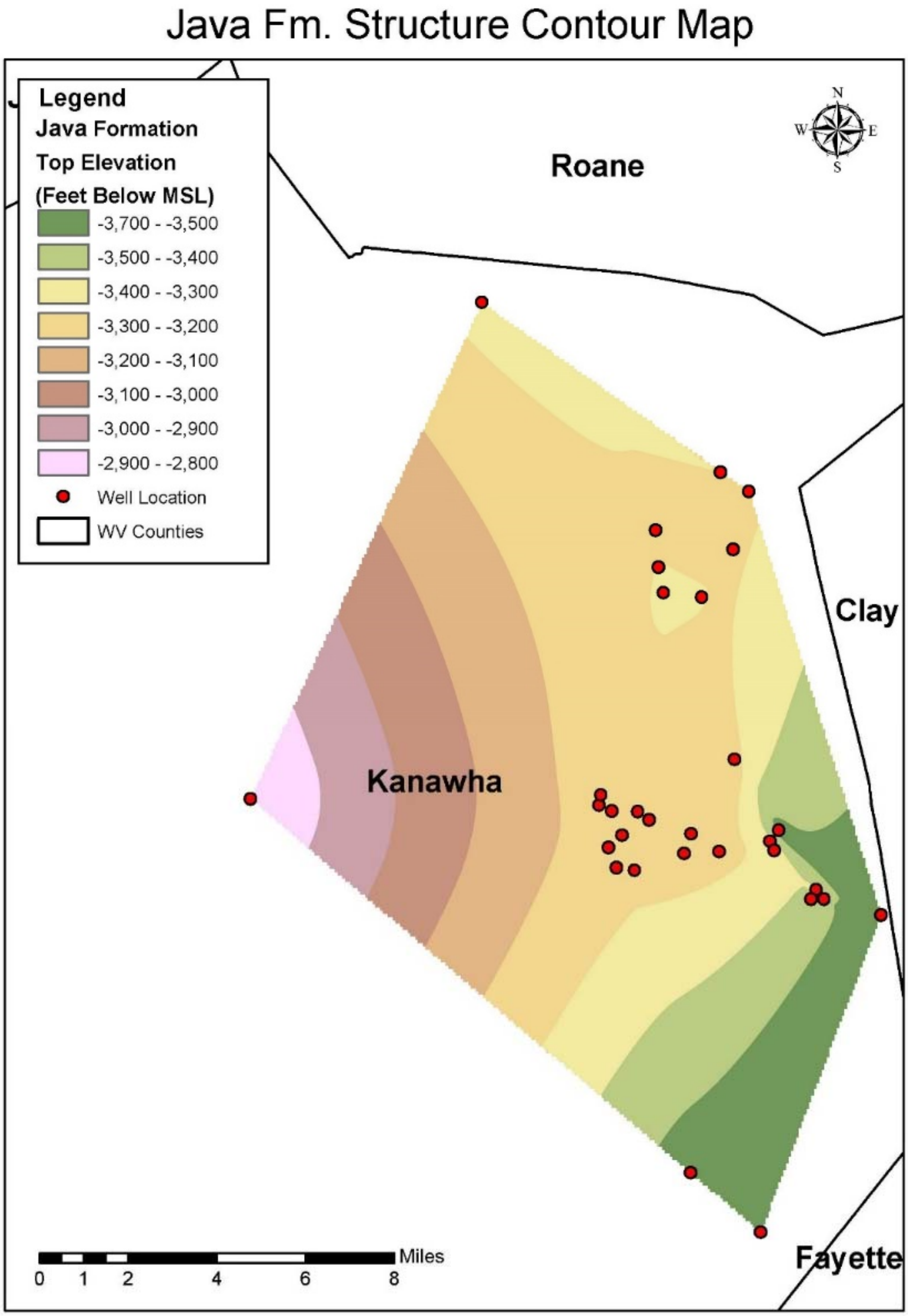


Figure 25: Java Formation
Structure Contour Map.

The West Falls/Angola Shale structure contour map (Figure 26) depicts the same gradual dip as previously mentioned to the southeast and to the east. A majority of the Angola is shown lying in the 3,400 to 3,500 feet below MSL range across the site. The underlying Rhinestreet Shale Member is depicted continuing the trend of dipping to the southeast and east in (Figure 27). The majority of the Rhinestreet falls within the 3,700 to 3,800 feet below mean sea level across the field.

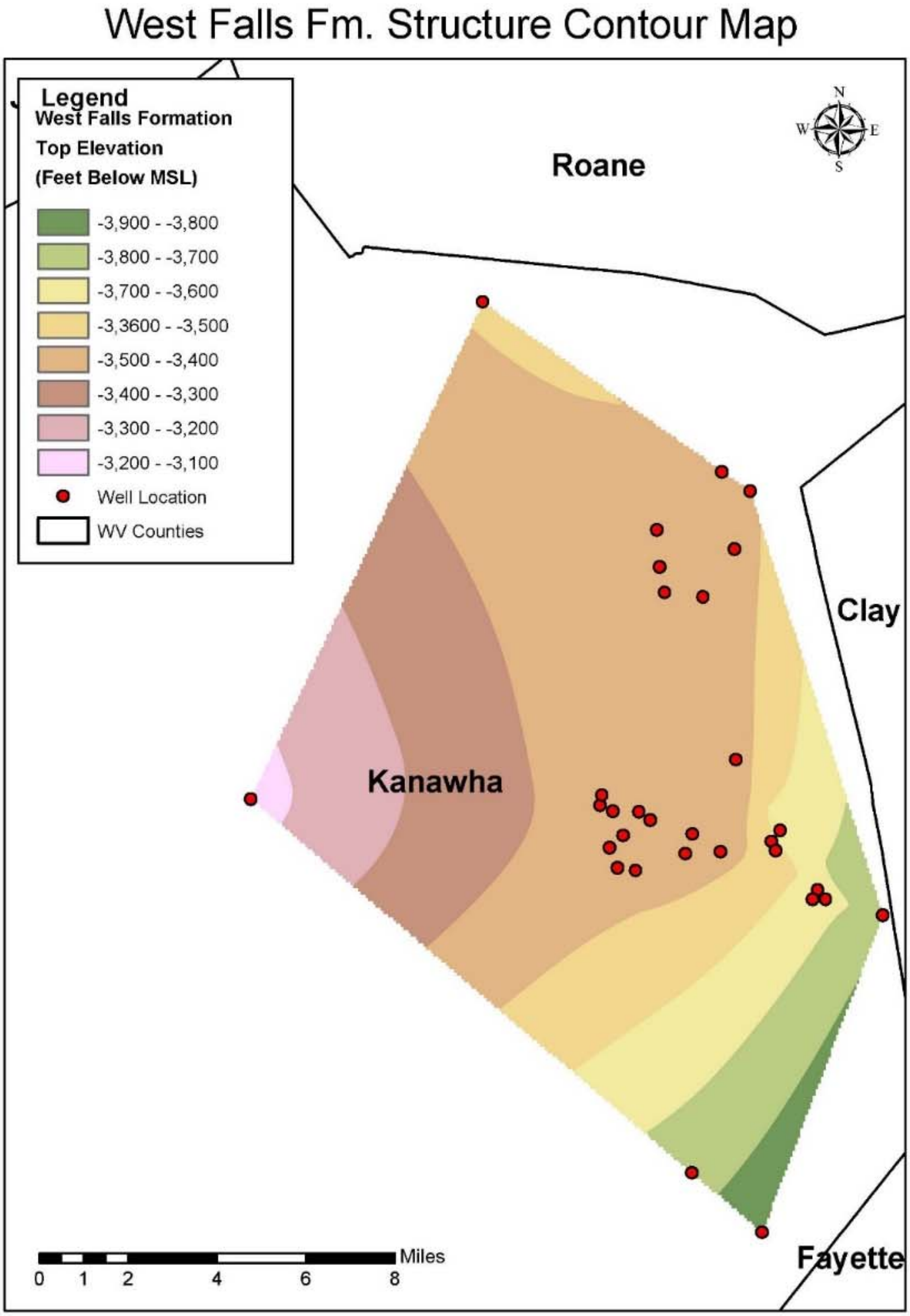


Figure 26: West Falls Formation
Structure Contour Map.

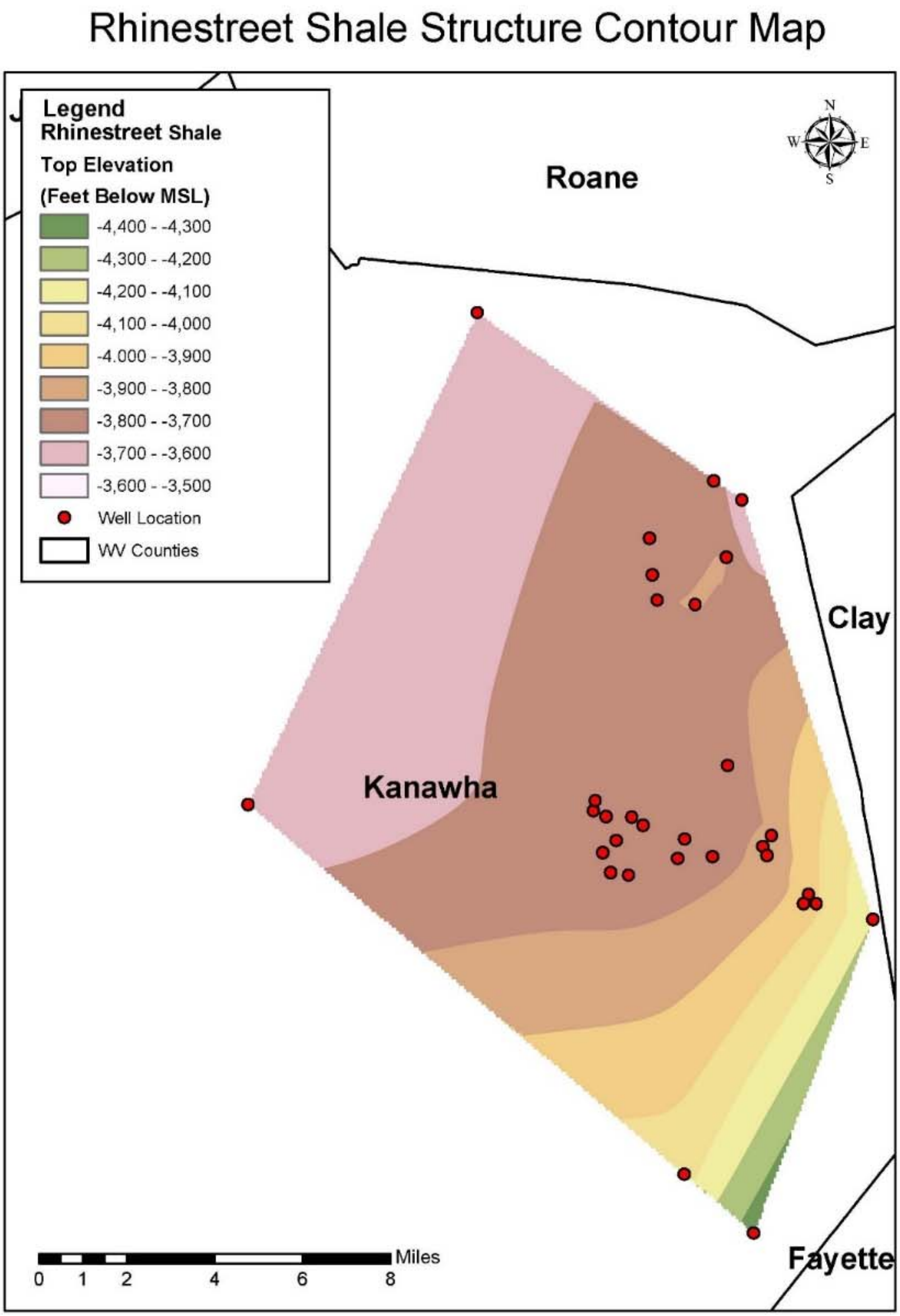


Figure 27: Rhinestreet Shale Structure Contour Map.

The Sonyea/Cashaqua Shale structure contour map (Figure 28) continues the southeast and eastward dipping trend. An area approximately 10 square miles in size along the southern portion of the field depicts a shallow ridge intersecting the middle of the field with a depth ranging from 3,900 to 4,100 feet below MSL. The Middlesex Shale Member, shown in (Figure 29), shows an overall similar dipping pattern with the ridge not showing as prominent as in the overlying Cashaqua Member.

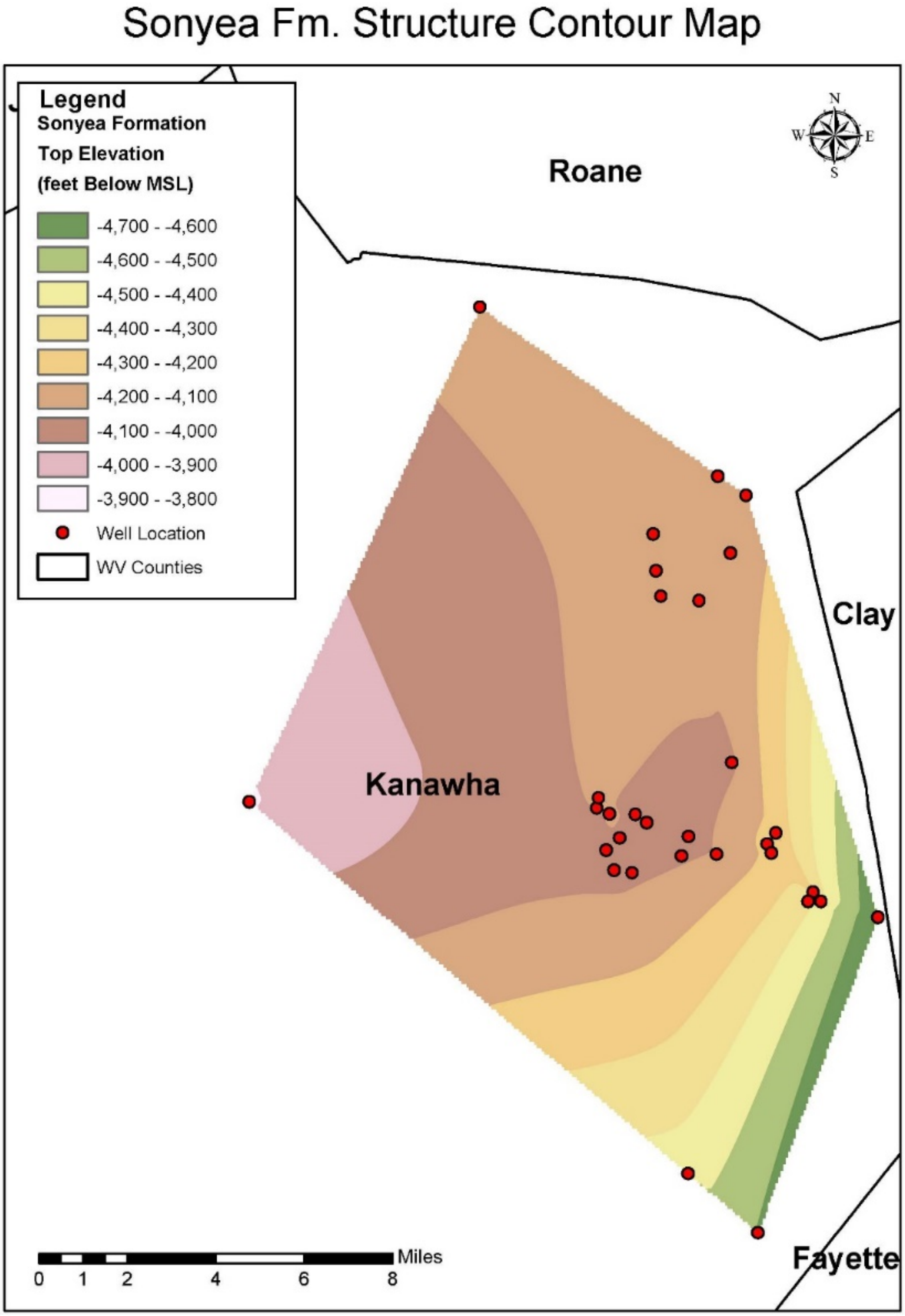


Figure 28: Sonyea Formation Structure Contour Map.

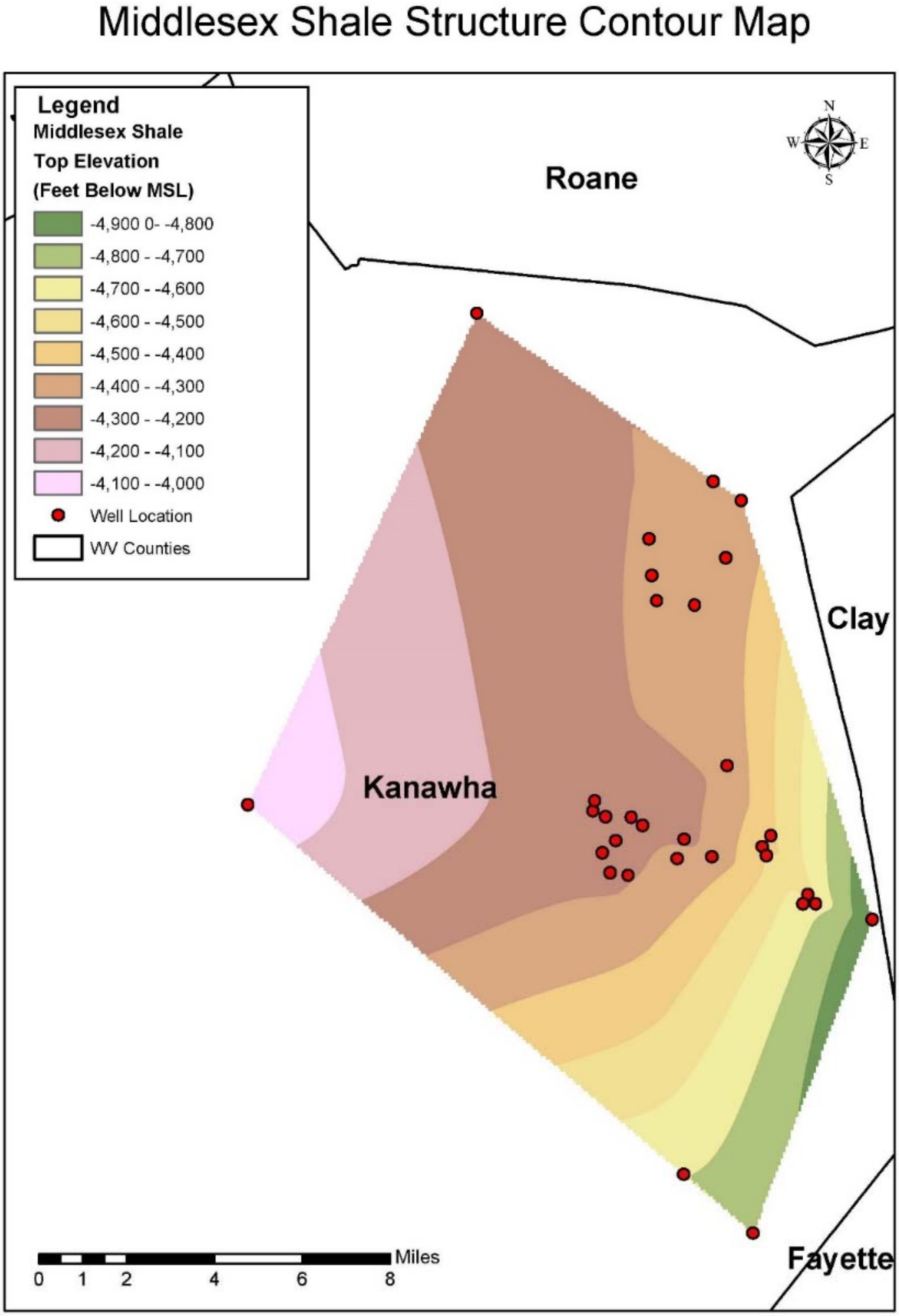


Figure 29: Middlesex Shale
Structure Contour Map.

The Genesee Formation/West River Shale structure contour map (Figure 30), like the previous formations and members, show the overall southeastern to eastern dip. The small ridge that was present in the overlying Sonyea Formation is still present, but much smaller in size (approximately 3 square miles). The Geneseo Shale member structure contour map (Figure 31) continues this trend as well with the exception of the small ridge is no longer depicted intersecting into the field.

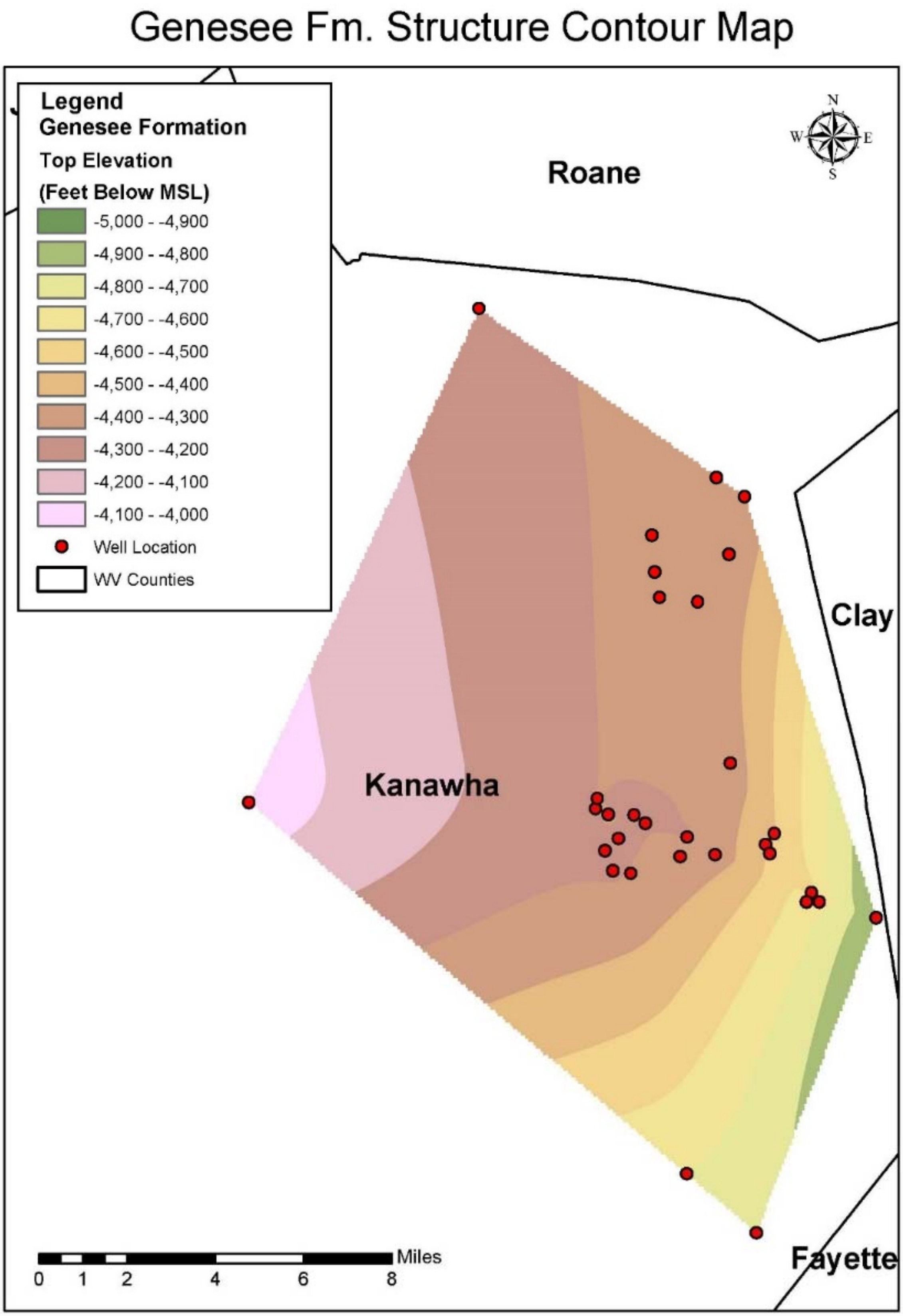


Figure 30: Genesee Formation/West River Shale
Structure Contour Map.

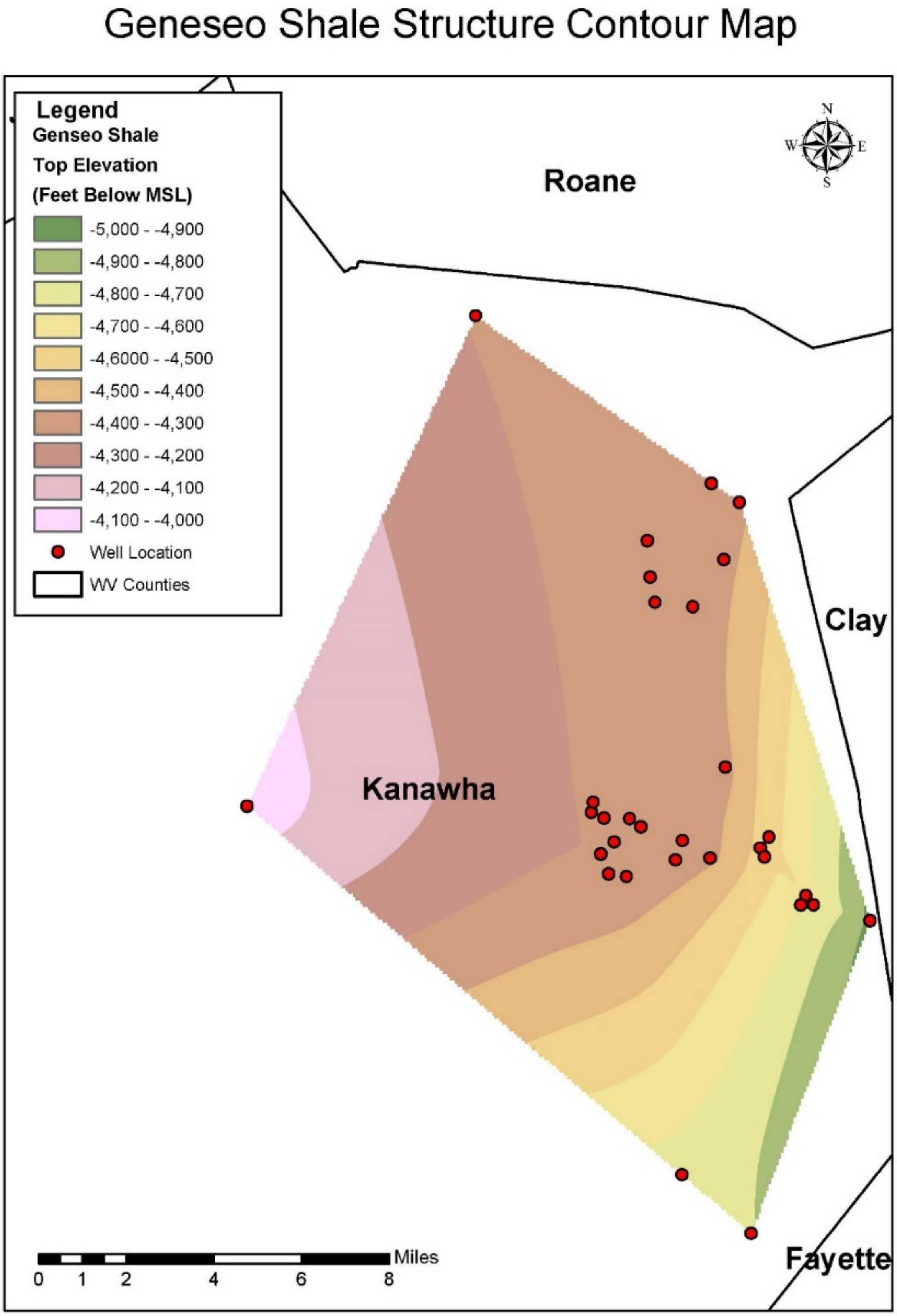


Figure 31: Genseo Shale
Structure Contour Map.

The Marcellus Shale structure contour map (Figure 32) depicts the same trend of a southeast to east dipping formation. A trough appears along the southeastern portion of the field in starting just south of well number 4703905966 and continuing to just northeast of the center of the field near well number 4703903909. The majority of the field falls within the 4,300 to 4,400 feet below MSL range with only a small portion of the site falling within the aforementioned trough which ranges from 4,500 to 4,700 feet below MSL.

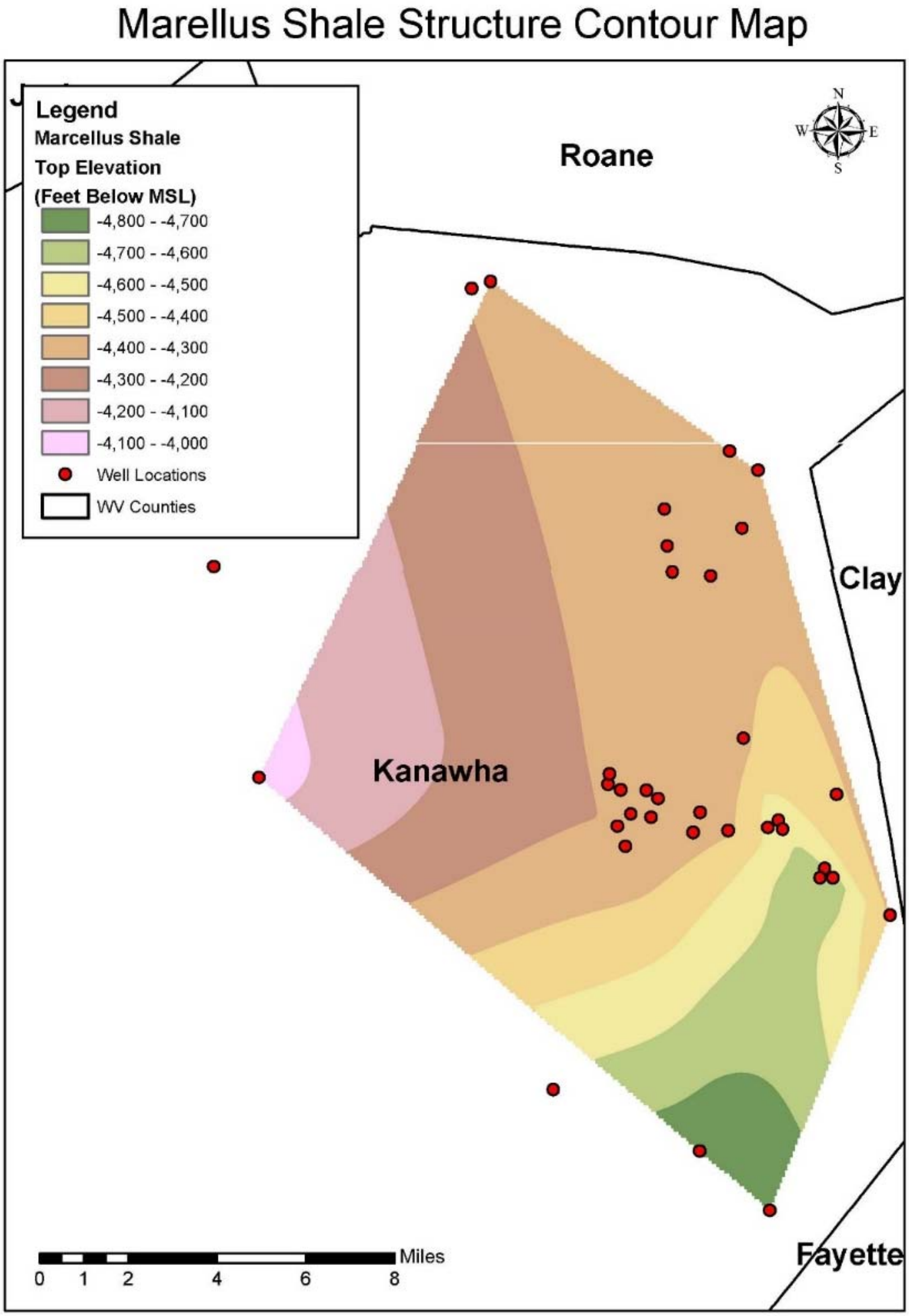


Figure 32: Marcellus Shale
Structure Contour Map.

The structure contour maps, like the isopach maps, appear to show the influence of the faults previously mentioned along the east and southeast of the field. Another potential influence on the formations within the field may be the Warfield anticline which protrudes into Kanawha County from the southwest and extends to just west northwest of the field. Another unnamed anticline along the northeast portion of the site may also be an influence on the structure of the formations within the Clendenin Field.

Well Production Analysis

Of the 696 wells located within the Clendenin Field only fifty of the wells were chosen to be analyzed for this study. The selection was based on the availability of scanned logs from each well and what the completion interval of the wells were (Devonian). The wells used contained completion intervals within the Lower Huron, Java Formation, Angola Shale, Rhinestreet Shale, and the Marcellus Shale. Of the production wells within the Clendenin Field only one well is a horizontal/deviated well, however, it is listed as being a storage well and not used for gas production therefore it was omitted from the study. Several wells did not include completion data or production data and were therefore omitted from the study as well. The remainder of the wells used for this study are listed as vertical wells and contain several formations throughout the completion interval. Since the completion intervals varied widely through the formations, they were broken down into Marcellus containing and Non-Marcellus containing wells.

Wells Containing Non-Marcellus Completion Intervals

Twenty-seven wells were completed throughout the field that did not produce from an interval within the Marcellus. Completion years for these wells ranged from 1982 to 2007 and initial production years ranged from 1983 to 2007. Wells in this category had reported completion intervals as within the Lower Huron Shale, the Lower Huron Shale to the Java Formation, Lower

Huron Shale to Angola Shale, Upper Devonian Undivided to Angola Shale, Lower Huron Shale to Rhinestreet Shale, and Upper Devonian Undivided to Rhinestreet Shale. Wells with these completion intervals had a reported production ranging from 2,130 mcf to 23,308 mcf for the first twelve months of production with an average production of 11,891 mcf and a median production of 12,428 mcf. The higher producing wells, 15,000 mcf and up, were mostly located to the north of the field with some outliers to the south and southeast. Some of the lowest producing wells were located in the middle of the field. Wells within the Non-Marcellus group are depicted in figure 33.

The better producing wells in Non-Marcellus group had a completion method reported as acid fracturing. However, the second lowest producing well in the group also had a reported completion method of acid fracturing. Therefore, the completion method doesn't appear to be the main driver of the increased production and location may be the biggest influence on production. Additionally, the interval completion size did not appear to have an influence on the production of the wells since many of the higher producing wells contained intervals only completed in the Lower Huron while others contained completion intervals ranging from the Upper Devonian Undivided to the Rhinestreet Shale. A complete table of the wells with the production data is provided in the Appendix.

Wells Containing Marcellus Completion Intervals

Twenty-Four wells were completed throughout the field that produce from an interval containing the Marcellus Shale. Completion years for these wells ranged from 1982 to 2009 with a majority of the wells being completed in the 2007 to 2008 range. Initial production years also ranged from 1982 to 2009. Wells in this category had reported completion intervals as being within the Lower Huron Shale to the Marcellus Shale, the Rhinestreet Shale to the Marcellus Shale, and Upper Devonian Undivided to the Marcellus Shale. Wells with these completion intervals had a reported production ranging from 11,714 mcf to 50,626 mcf for the first twelve months of production with an average production of 21,538 mcf and a median production of 19,537 mcf. The majority higher producing wells, 15,000 mcf and up, were mostly located to in the southern portion of the field with some of the lower wells to the north. Some of the lowest producing wells were located in the middle and southeast of the field. Wells within the Marcellus containing group are depicted in Figure 33.

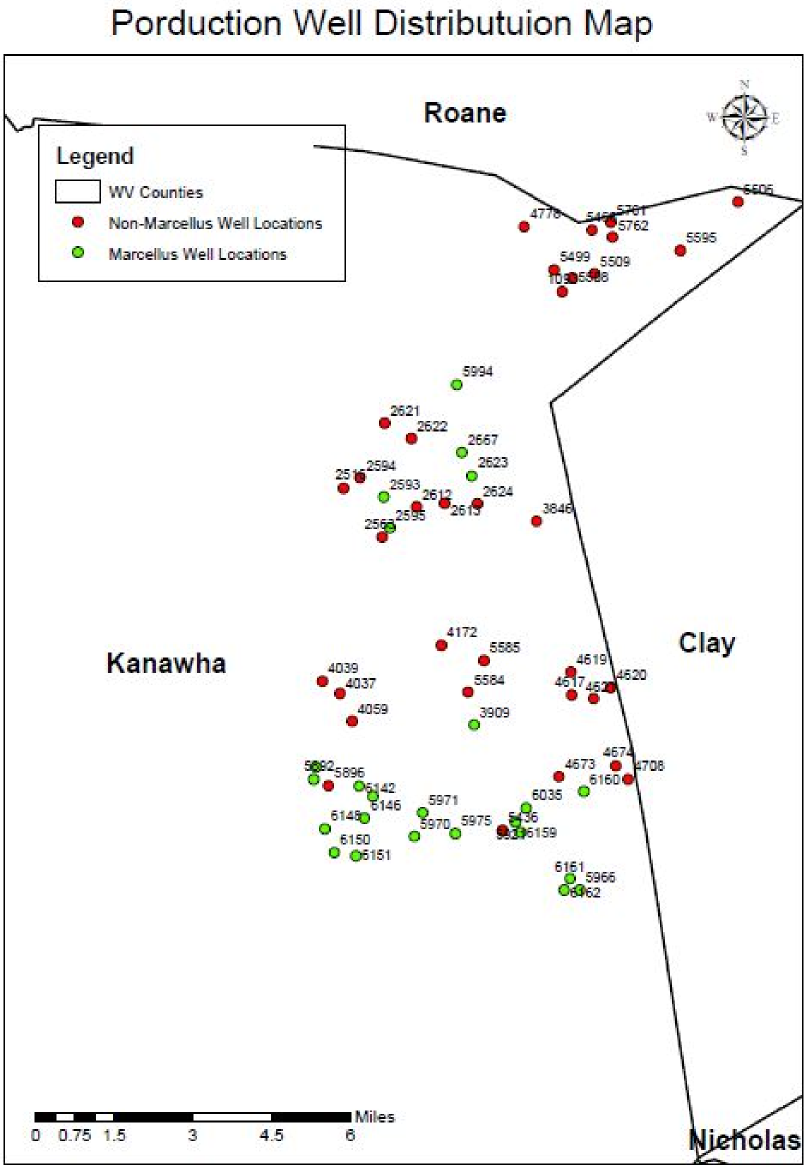


Figure 33: Production Well Distribution Map.

The top-producing and lowest-producing wells in Marcellus containing group had a completion method reported as acid fracturing as with the previous wells. Additionally, all wells utilized in this assessment were documented as being vertical wells. Therefore, the completion methods still don't appear to be the main driving influence of the increased production and as with the Non-Marcellus wells location may be the biggest influence on production. Like the Non-Marcellus group, interval completion size did not appear to have an influence on the production of the wells since the highest producing well and the lowest producing well contained the same Upper Devonian Undivided to Marcellus Shale completion interval. A complete table of the wells with the production data is provided in the Appendix.

CHAPTER V: DISCUSSION & CONCLUSIONS

The A-A' stratigraphic cross section which transects the field from west to east, shows the formations in a generally "flat" orientation across the site with little or no ridges or troughs with the exception of a trough that appears along the eastern portion of the cross section in the vicinity of well number 4703905921 at the base of the Sonyea Formation. The same trough is evident through the Genesee Formation, the Marcellus Shale, and continues into the Onondaga Limestone. Within the trough, the formations are thicker. These formations in this area show a gradual increase in thickness eastward in cross-section A-A' and increases to 20 to 30 and even 50 feet more at wells at this low area. The same area of thickening is evident in cross-section B-B'. The Isopach maps for the Sonyea Formation through the Marcellus Shale also depict isolated areas of thickening in those areas. Structure maps for the Sonyea Formation, Genesee Formation, and Marcellus Shale further detail these areas showing the topographic low trending to the southeast. An overlay of the Rome Trough and associated faults through Kanawha County places the Eastern Fault Margin transecting the field in this general vicinity. An additional smaller unnamed fault is depicted to the northwest of the area. Faulting and reactivation of old faults within the area, especially the Cambrian-aged East Margin Fault of the Rome Trough (Dinterman, 2017), prior to deposition of the sediments that make up these formations is believed to have occurred forming the trough where additional sediments were deposited and created these areas where thickening of the formations occurred. The Overlay depicting the location of the faults in reference to the well locations is provided below in Figure 34.

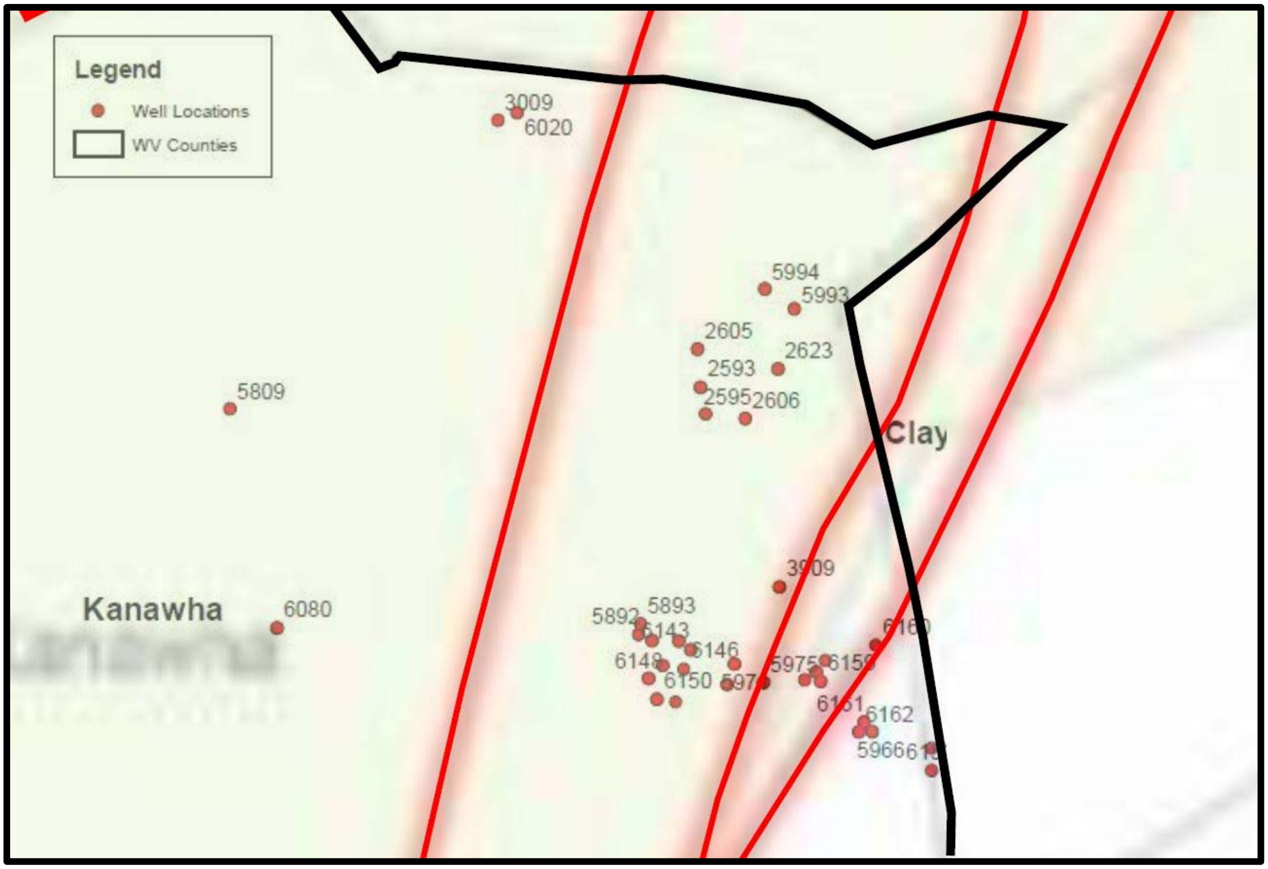


Figure 34: Image overlay of the Rome Trough and Associated Faults (Outlined in Red) over the Clendenin Field. Adapted from Dinterman, 2017.

Stratigraphic Cross Section B-B' appears to have an undulating pattern through all of the formations throughout the field. Overall the formations and their associated members appear to maintain a gradual thickening trend across field toward the south. These undulations depicted in the B-B' cross-section may also be linked to the faults that transect the field where areas of thickening are possibly sediment basins created after faulting.

Structure contour maps showed an overall southeastward dip trend with the tops of the formations becoming gradually shallower to the west and west-northwest. Looking at the deepening of the tops of the formations to the southeast in the vicinity of the aforementioned faults, this could also represent the effects of normal faulting along the Eastern Fault Margin prior to and during the early stages of deposition of the formations. Other nearby structures that may have a potential effect on the formation throughout the field includes the Warfield Anticline to the southwest and an unnamed anticline to the north-northeast as depicted in Figure 35 below.

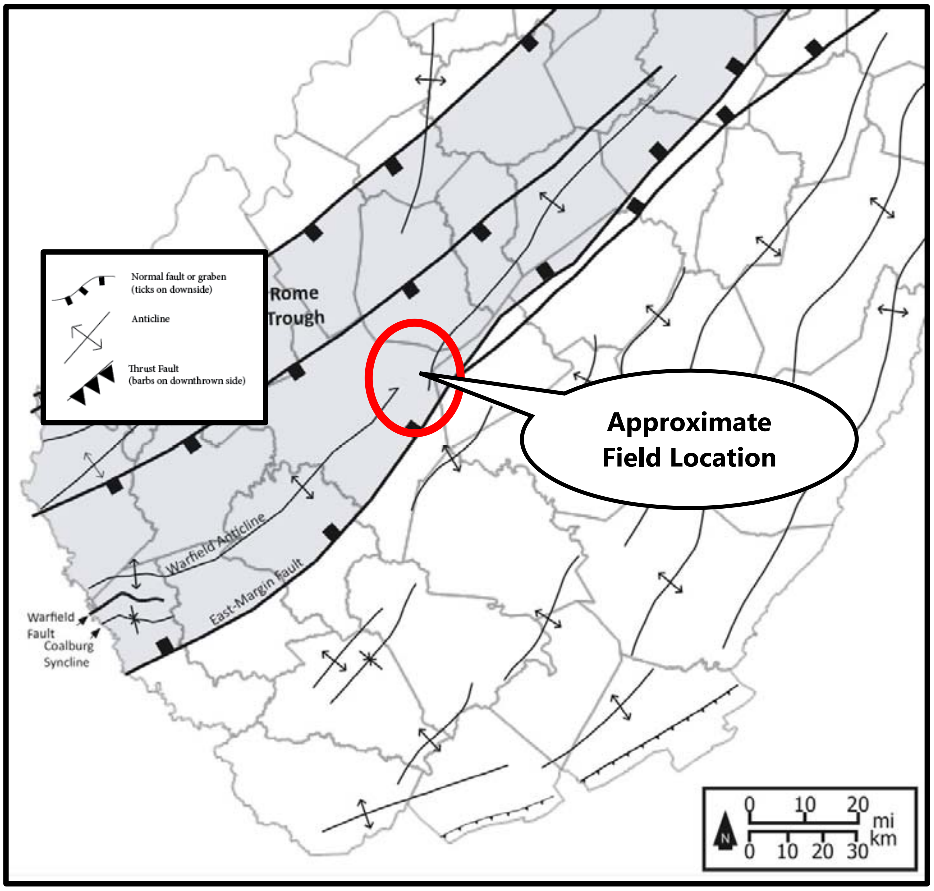


Figure 35: Warfield Anticline, Rome Trough, and East-Margin Fault (Thomas, 1991; Shumaker, 1993; Gao et al., 2000; Coolen, 2003).

Production throughout the field had an overall range of 2,130 mcf to 50,626 mcf respectively. The Non-Marcellus containing well production was generally half of those that did contain Marcellus in the completion interval. Non-Marcellus containing production wells appeared to be more focused to the north and center of the Clendenin Field than those containing the Marcellus. The Marcellus containing wells were more focused to the south of the field. The three highest producing wells of the dataset (4703905966, 4703906161, and 4703906150) were some of the furthest south wells in the field. Each of the high producing wells also fell within the downward dip of the formations based on the structure contour maps. These areas are also noted as areas of thickening for many of the formations. A box plot of the data is show below in Figure 36. Tables summarizing production from Non-Marcellus containing wells and Marcellus containing wells are provided in Appendix B.

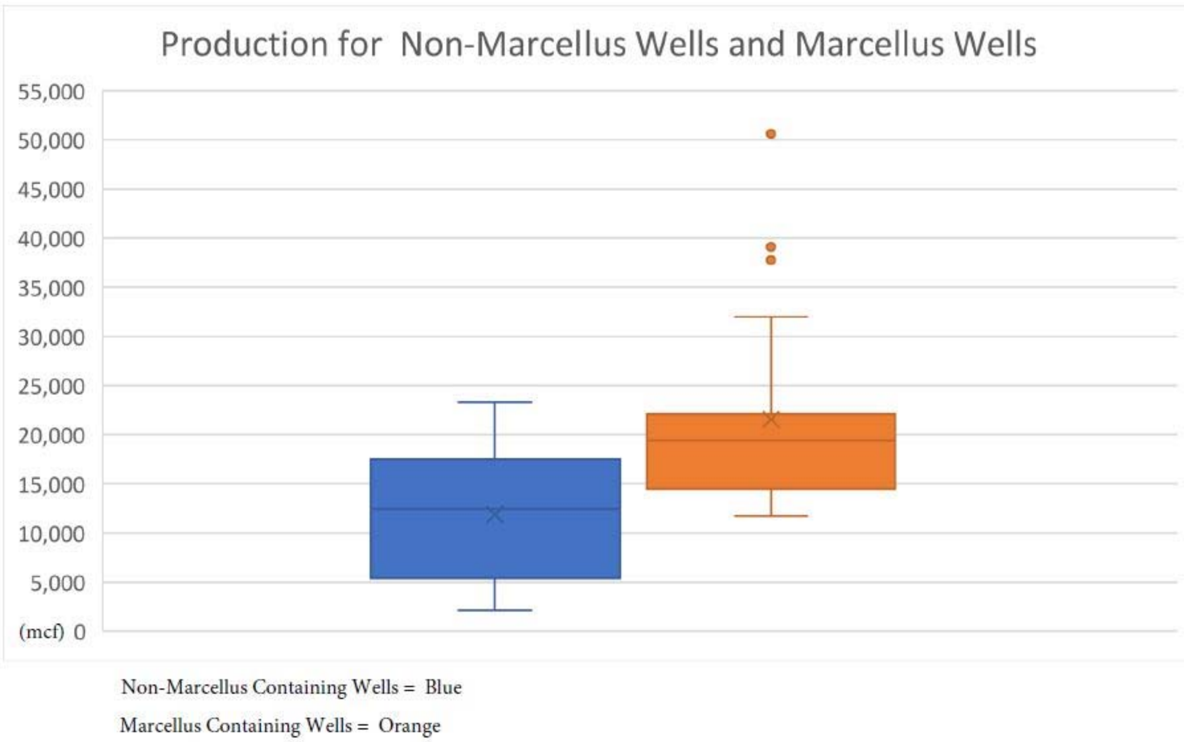


Figure 36: Box plot showing production for Non-Marcellus and Marcellus containing wells.

The highest producing well in the Non-Marcellus wells was located to the northern most portion of the field with a production of 23,308 mcf. The surrounding wells also produced best within the group and had generally better production than the southern wells of the group. These wells similar to the higher producing southern wells of the Marcellus containing group, are in the vicinity of the inner unnamed fault depicted in figure 34 above. They are also near the unnamed anticline depicted in Figure 35 above.

Based on the location of high and low producing wells, the following hypotheses can be made. The wells nearest fault zones and anticlines are within a topographic low that created a sediment trap resulting in thicker units within this area. With the thicker units comes more volume for the completed interval to extract gas from. The formations and members within this vicinity also potentially have more fractured and fissured zones due to the tectonic activity near those features which makes the gas more readily and easily extracted. This is evident based on the higher production from wells in the vicinity of these faults and features within the thicker areas of the formations. However, the lower producing wells are also within a similar distance to the faults and anticlines as the higher producing wells, but those wells are to the west of those features. This could indicate that those wells penetrate the units at areas that were topographically higher at the time of deposition resulting in thinner sections at those locations.

Through the use of available geophysical well logs for existing wells in the study area, the construction of stratigraphic cross-sections transecting the field were used to visualize the general stratigraphy of the subsurface along those profile lines. When used in conjunction with the isopach and structure contour maps which were also produce based on geophysical well logging data, a better understanding of the subsurface throughout the entire area helps identify areas of potential future production.

Review of the aforementioned maps and their proximity to faults and anticlines transecting the field, assumptions regarding the deposition and resulting unit thickness' can be made. Further gas exploration along the faults and anticlines to the east of the field is recommended. These areas, based on the results of this study, produced better returns than other wells to the west where the units thinned.

Non-Marcellus producing wells overall produced less, on average half the amount, than the Marcellus containing wells. The Non-Marcellus wells had produced less from the wells to the southwest where the formations thin. The Non-Marcellus wells that produced the best were located to the northeast where the units thicken and come within close proximity to the faults transecting the field. It is recommended that the Non-Marcellus wells be advanced deeper into the Marcellus Shale to increase production from those wells.

All of the producing wells within the field area reported as being vertical wells. Horizontal drilling within wells in neighboring fields produce nearly double from shallower units according to data from the WVGES Pipeline reporting system. Within Roane County to the north, horizontal wells completed within the Lower Huron have produced from 48,000 mcf to 76,000 mcf in the first twelve months of production. It is recommended that horizontal drilling be considered within the field as a means to increase production.

The conclusions of this study are:

1. Based on the results of this study, wells in the vicinity of the faults and anticlines to the east of the field produced better returns than other wells to the west where the units thinned. Further gas exploration along the faults and anticlines to the east of the field in these areas is recommended.
2. Non-Marcellus producing wells overall produced less, on average half the amount, than the Marcellus containing wells. It is recommended that the Non-Marcellus wells be advanced deeper into the Marcellus Shale to increase production from those wells.
3. All of the producing wells within the field area reported as being vertical wells. Horizontal drilling within wells in neighboring fields produce nearly

double from shallower units according to data from the WVGES Pipeline reporting system. It is recommended that horizontal drilling be considered within the field as a means to increase production.

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APPENDIX A: FORMATION AND MEMBERS

SUBSEA ELEVATION AND THICKNESSES

Well ID No.	Ohio Shale Top Elevation	Ohio Shale Bottom Elevation	Thickness
4703906080	2310	3857	1547
4703906020	2398	4391	1993
4703906148	2382	4392	2010
4703906150	2542	4556	2014
4703906151	2106	4120	2014
4703905893	2198	4214	2016
4703906142	2528	4544	2016
4703905892	2462	4480	2018
4703905899	1979	4000	2021
4703905896	2111	4134	2023
4703902605	2492	4516	2024
4703905970	2350	4378	2028
4703906143	2522	4552	2030
4703905971	2012	4046	2034
4703905975	2048	4084	2036
4703905987	2980	5019	2039
4703902606	2624	4670	2046
4703902593	2036	4083	2047
4703902595	2421	4470	2049
4703905993	1993	4044	2051
4703905921	2438	4490	2052
4703906159	2646	4700	2054
4703903909	2646	4702	2056
4703905994	2258	4322	2064
4703902623	2077	4145	2068
4703906161	2778	4852	2074
4703905952	2914	4990	2076
4703906162	2434	4530	2096
4703905966	2598	4700	2102
4703906035	2448	4708	2260
47039066152	2450	4890	2440

Well ID No.	Java Formation Top Elevation	Java Formation Bottom Elevation	Thickness
4703902593	4083	4271	188
4703902595	4470	4618	148
4703902605	4516	4712	196
4703902606	4670	4832	162
4703902623	4145	4293	148
4703903909	4702	4857	155
4703905892	4480	4674	194
4703905893	4214	4426	212
4703905896	4134	4326	192
4703905899	4000	4192	192
4703905921	4490	4680	190
4703905966	4774	4922	148
4703905970	4378	4577	199
4703905971	4046	4244	198
4703905975	4084	4286	202
4703905993	4044	4243	199
4703905994	4322	4511	189
4703906142	4544	4740	196
4703906143	4552	4749	197
4703906148	4392	4588	196
4703906150	4556	4750	194
4703906159	4700	4908	208
4703906161	4852	5062	210
4703906162	4530	4756	226
4703906035	4708	4842	134
4703906151	4120	4310	190
4703906020	4391	4572	181
47039066152	4890	5100	210
4703905987	5019	5240	221
4703905952	4990	5199	209
4703906080	3857	4216	359

Well ID No.	West Falls Formation Top Elevation	West Falls Formation Bottom Elevation	Thickness
4703902593	4271	4890	619
4703902595	4618	5279	661
4703902605	4712	5343	631
4703902606	4832	5514	682
4703902623	4293	4970	677
4703903909	4857	5542	685
4703905892	4674	5284	610
4703905893	4426	5100	674
4703905896	4326	5034	708
4703905899	4192	4804	612
4703905921	4680	5376	696
4703905966	4922	5724	802
4703905970	4577	5232	655
4703905971	4244	4876	632
4703905975	4286	4934	648
4703905993	4243	4876	633
4703905994	4511	5145	634
4703906142	4740	5360	620
4703906143	4749	5372	623
4703906148	4588	5206	618
4703906150	4750	5366	616
4703906159	4908	5578	670
4703906161	5062	5752	690
4703906162	4756	5472	716
4703906035	4842	5400	558
4703906151	4310	4932	622
4703906020	4572	5139	567
47039066152	5100	6004	904
4703905987	5582	5982	400
4703905952	5199	5890	691
4703906080	4216	4948	732

Well ID No.	Angola Shale Top Elevation	Angola Shale Bottom Elevation	Thickness
4703902593	4271	4561	290
4703902595	4618	4951	333
4703902605	4712	5001	289
4703902606	4832	5170	338
4703902623	4293	4668	375
4703903909	4857	5182	325
4703905892	4674	4960	286
4703905893	4426	4704	278
4703905896	4326	4612	286
4703905899	4192	4478	286
4703905921	4680	4964	284
4703905966	4922	5258	336
4703905970	4577	4861	284
4703905971	4244	4528	284
4703905975	4286	4579	293
4703905993	4243	4354	111
4703905994	4511	4799	288
4703906142	4740	5025	285
4703906143	4749	5035	286
4703906148	4588	4872	284
4703906150	4750	5036	286
4703906159	4908	5197	289
4703906161	5062	5445	383
4703906162	4756	5036	280
4703906035	4842	4975	133
4703906151	4310	4594	284
4703906020	4572	4676	104
47039066152	5100	5514	414
4703905987	5240	5731	491
4703905952	5199	5500	301
4703906080	4216	4680	464

Well ID No.	Rhinestreet Shale Top Elevation	Rhinestreet Shale Bottom Elevation	Thickness
4703902593	4561	4890	329
4703902595	4951	5279	328
4703902605	5001	5343	342
4703902606	5170	5514	344
4703902623	4668	4970	302
4703903909	5182	5542	360
4703905892	4960	5284	324
4703905893	4704	5100	396
4703905896	4612	5034	422
4703905899	4478	4804	326
4703905921	4964	5376	412
4703905966	5258	5724	466
4703905970	4861	5232	371
4703905971	4528	4876	348
4703905975	4579	4934	355
4703905993	4354	4876	522
4703905994	4799	5145	346
4703906142	5025	5360	335
4703906143	5035	5372	337
4703906148	4872	5206	334
4703906150	5036	5366	330
4703906159	5197	5578	381
4703906161	5445	5752	307
4703906162	5036	5472	436
4703906035	4975	5400	425
4703906151	4594	4932	338
4703906020	4676	5139	463
47039066152	5514	6004	490
4703905987	5731	5982	251
4703905952	5500	5890	390
4703906080	4680	4948	268

Well ID No.	Sonyea Formation Top Elevation	Sonyea Formation Bottom Elevation	Thickness
4703902593	4890	5117	227
4703902595	5279	5500	221
4703902605	5343	5560	217
4703902606	5514	5750	236
4703902623	4970	5212	242
4703903909	5542	5795	253
4703905892	5284	5514	230
4703905893	5100	5260	160
4703905896	5034	5202	168
4703905899	4804	5028	224
4703905921	5376	5648	272
4703905966	5724	5912	188
4703905970	5232	5484	252
4703905971	4876	5092	216
4703905975	4934	5158	224
4703905993	4876	5102	226
4703905994	5145	5362	217
4703906142	5360	5592	232
4703906143	5372	5594	222
4703906148	5206	5420	214
4703906150	5366	5580	214
4703906159	5578	5878	300
4703906161	5752	6020	268
4703906162	5472	5784	312
4703906035	5400	5654	254
4703906151	4932	5154	222
4703906020	5202	5326	124
47039066152	6004	6220	216
4703905987	5982	6130	148
4703905952	5890	6138	248
4703906080	4948	5096	148

Well ID No.	Cashaqua Shale Top Elevation	Cashaqua Shale Bottom Elevation	Thickness
4703902593	4890	5095	205
4703902595	5279	5483	204
4703902605	5343	5545	202
4703902606	5514	5740	226
4703902623	4970	5202	232
4703903909	5542	5766	224
4703905892	5284	5488	204
4703905893	5100	5233	133
4703905896	5034	5166	132
4703905899	4804	5008	204
4703905921	5376	5634	258
4703905966	5724	5904	180
4703905970	5232	5472	240
4703905971	4876	5083	207
4703905975	4934	5146	212
4703905993	4876	5084	208
4703905994	5145	5342	197
4703906142	5360	5576	216
4703906143	5372	5574	202
4703906148	5206	5404	198
4703906150	5366	5564	198
4703906159	5578	5864	286
4703906161	5752	6010	258
4703906162	5472	5768	296
4703906035	5400	5640	240
4703906151	4932	5136	204
4703906020	5139	5316	177
47039066152	6004	6212	208
4703905987	5982	6118	136
4703905952	5890	6132	242
4703906080	4948	5082	134

Well ID No.	Middlesex Shale Top Elevation	Middlesex Shale Bottom Elevation	Thickness
4703902593	5095	5117	22
4703902595	5483	5500	17
4703902605	5545	5560	15
4703902606	5740	5750	10
4703902623	5202	5212	10
4703903909	5766	5795	29
4703905892	5488	5514	26
4703905893	5233	5260	27
4703905896	5166	5202	36
4703905899	5008	5028	20
4703905921	5634	5648	14
4703905966	5904	5912	8
4703905970	5472	5484	12
4703905971	5083	5092	9
4703905975	5146	5158	12
4703905993	5084	5102	18
4703905994	5342	5362	20
4703906142	5576	5592	16
4703906143	5574	5594	20
4703906148	5404	5420	16
4703906150	5564	5580	16
4703906159	5864	5878	14
4703906161	6010	6020	10
4703906162	5768	5784	16
4703906035	5640	5654	14
4703906151	5136	5154	18
4703906020	5316	5326	10
47039066152	6212	6220	8
4703905987	6118	6130	12
4703905952	6132	6138	6
4703906080	5082	5096	14

Well ID No.	Genesee Formation Top Elevation	Genesee Formation Bottom Elevation	Thickness
4703902593	5118	5162	44
4703902595	5500	5545	45
4703902605	5560	5612	52
4703902606	5750	5767	17
4703902623	5211	5250	39
4703903909	5795	5822	27
4703905892	5514	5556	42
4703905893	5260	5288	28
4703905896	5202	5214	12
4703905899	5028	5076	48
4703905921	5648	5668	20
4703905966	5912	5970	58
4703905970	5484	5510	26
4703905971	5092	5142	50
4703905975	5158	5218	60
4703905993	5102	5154	52
4703905994	5362	5413	51
4703906142	5592	5644	51
4703906143	5594	5630	36
4703906148	5420	5466	46
4703906150	5580	5634	54
4703906159	5878	5946	68
4703906161	6020	6078	58
4703906162	5760	5836	76
4703906035	5654	5742	88
4703906151	5154	5202	48
4703906020	5326	5374	48
47039066152	6220	6264	44
4703905987	6130	6190	60
4703905952	6138	6216	78
4703906080	5096	5118	22

Well ID No.	Geneseo Shale Top Elevation	Geneseo Shale Bottom Elevation	Thickness
4703902593	5150	5162	14
4703902595	5530	5545	15
4703902605	5600	5612	12
4703902606	5736	5767	31
4703902623	5234	5250	16
4703903909	5822	5822	0
4703905892	5536	5556	20
4703905893	5270	5288	18
4703905896	5214	5214	0
4703905899	5060	5076	16
4703905921	5657	5668	11
4703905966	5952	5970	18
4703905970	5494	5510	16
4703905971	5124	5142	18
4703905975	5200	5218	18
4703905993	5140	5154	14
4703905994	5400	5413	13
4703906142	5626	5644	18
4703906143	5618	5630	12
4703906148	5450	5466	16
4703906150	5616	5634	18
4703906159	5928	5946	18
4703906161	6060	6078	18
4703906162	5814	5836	22
4703906035	5724	5742	18
4703906020	5362	5374	12
47039066152	6240	6264	24
4703905987	6172	6190	18
4703905952	6188	6216	28
4703906080	5102	5118	16

Well ID No.	West River Shale Top Elevation	West River Shale Bottom Elevation	Thickness
4703902593	5118	5150	32
4703902595	5500	5530	30
4703902605	5560	5600	40
4703902606	5750	5767	17
4703902623	5211	5234	23
4703903909	5795	5831	36
4703905892	5514	5542	28
4703905893	5260	5280	20
4703905896	5202	5214	12
4703905899	5028	5066	38
4703905921	5648	5692	44
4703905966	5912	5956	44
4703905970	5484	5510	26
4703905971	5092	5130	38
4703905975	5158	5206	48
4703905993	5102	5150	48
4703905994	5362	5400	38
4703906142	5592	5644	52
4703906143	5594	5630	36
4703906148	5420	5462	42
4703906150	5580	5634	54
4703906159	5878	5928	50
4703906161	6020	6078	58
4703906162	5760	5825	65
4703906035	5654	5704	50
4703906151	5154	5202	48
4703906020	5326	5362	36
47039066152	6220	6240	20
4703905987	6130	6172	42
4703905952	6138	6188	50
4703906080	5096	5102	6

Well ID No.	Marcellus Shale Top Elevation	Marcellus Shale Bottom Elevation	Thickness
4703902593	5148	5192	44
4703902595	5532	5571	39
4703902605	5620	5652	32
4703902606	5767	5789	22
4703902623	5233	5281	48
4703903909	5822	5858	36
4703905436	5108	5146	38
4703905892	5535	5586	51
4703905893	5273	5316	43
4703905896	5208	5245	37
4703905899	5055	5108	53
4703905921	5720	5778	58
4703905966	5949	6016	67
4703905970	5508	5545	37
4703905971	5120	5176	56
4703905975	5201	5250	49
4703905993	5155	5172	17
4703905994	5413	5437	24
4703906142	5620	5672	52
4703906143	5620	5663	43
4703906146	5235	5273	38
4703906148	5448	5496	48
4703906150	5615	5672	57
4703906159	5933	5981	48
4703906160	5457	5518	61
4703906161	6071	6114	43
4703906162	5815	5880	65

APPENDIX B: WELL PRODUCTION TABLES

Production From Wells Not Completed in the Marcellus Shale

Well ID No.	**Completion Formation**	**Reported Interval Thickness (Feet)**	**Completion Year**	**Initial Production Year**	**First 12 Months Production (mcf)**	**Completion Method**
4703903846	Up Dev-Rhinestreet	2,872	1982	1983	2,130	Unknown
4703904621	Up Dev-Angola	170	1989	1992	3,818	Acid + Frac
4703904619	Lower Huron-Rhinestreet	301	1989	2003	3,923	Frac
4703905584	Up Dev-Lower Huron	770	2003	2004	4,278	Acid + Frac
4703904673	Lower Huron-Rhinestreet	112	1989	1991	4,549	Acid + Frac
4703904059	Lower Huron-Angola	1,184	1984	1985	5,109	Frac
4703905506	Up Dev-Lower Huron	440	2002	2002	5,478	Acid + Frac
4703905585	Lower Huron	466	2003	2004	6,396	Frac
4703904620	Up Dev-Rhinestreet	150	1989	1990	7,270	Acid + Frac
4703904172	Lower Huron	30	1985	1988	7,804	Open Hole
4703904039	Lower Huron-Java	400	1984	1988	8,416	Frac
4703905595	Up Dev-Rhinestreet	650	2003	2003	8,585	Acid + Frac
4703904674	Lower Huron-Angola	274	1989	1989	11,949	Acid + Frac
4703904037	Lower Huron-Java	425	1984	1986	12,907	Frac
4703905508	Lower Huron	385	2002	2002	13,783	Acid + Frac
4703905466	Up Dev-Lower Huron	797	2002	2002	13,956	Acid + Frac
4703904778	Lower Huron-Rhinestreet	1,345	2004	2004	14,813	Acid + Frac
4703904617	Lower Huron-Angola	6	1988	1989	15,292	Acid + Frac
4703905509	Up Dev-Lower Huron	301	2002	2002	15,816	Acid + Frac
4703905896	Up Dev-Rhinestreet	306	2007	2007	17,381	Frac
4703905499	Up Dev-Angola	248	2002	2002	17,886	Acid + Frac
4703901093	Lower Huron	256	2002	2002	18,349	Acid + Frac
4703905762	Up Dev-Rhinestreet	455	2005	2006	21,539	Acid + Frac
4703905436	Lower Huron	744	2006	2002	22,097	Acid + Frac
4703904708	Up Dev-Rhinestreet	7	1990	1991	22,333	Acid + Frac
4703905761	Up Dev-Rhinestreet	448	2005	2006	23,308	Acid + Frac

Production From Wells Completed in the Marcellus Shale

Well ID No.	Completion Formation	Reported Interval Thickness (Feet)	Completion Year	Initial Production Year	First 12 Months Production (mcf)	Completion Method
4703903909	Up Dev-Marcellus	720	1982	1982	11,714	Acid + Frac
4703906160	Lower Huron-Marcellus	20	2008	2009	11,806	Acid + Frac
4703905994	Rhinestreet-Marcellus	28	2008	2007	12,424	Acid + Frac
4703906143	Rhinestreet-Marcellus	76	2008	2008	13,721	Unknown
4703906146	Lower Huron-Marcellus	96	2008	2008	13,966	Acid + Frac
4703905971	Up Dev-Marcellus	84	2007	2007	14,473	Frac
4703906035	Up Dev-Marcellus	96	2008	2008	15,148	Acid + Frac
4703905893	Lower Huron-Marcellus	61	2007	2007	16,463	Acid + Frac
4703905970	Up Dev-Marcellus	62	2007	2007	16,740	Acid + Frac
4703906142	Up Dev-Marcellus	89	2008	2008	17,275	Unknown
4703905892	Lower Huron-Marcellus	80	2007	2007	19,263	Acid + Frac
4703905921	Lower Huron-Marcellus	184	2007	2007	19,437	Frac
4703905993	Lower Huron-Marcellus	10	2007	2007	20,206	Acid + Frac
4703906159	Lower Huron-Marcellus	470	2008	2009	20,477	Frac
4703906151	Lower Huron-Marcellus	110	2008	2008	20,560	Acid + Frac
4703905975	Up Dev-Marcellus	84	2007	2007	20,576	Acid + Frac
4703906162	Up Dev-Marcellus	100	2008	2009	21,306	Frac
4703905436	Up Dev-Marcellus	744	2006	2006	22,097	Acid + Frac
4703906148	Lower Huron-Marcellus	67	2008	2008	28,216	Unknown
4703905899	Lower Huron-Marcellus	100	2006	2007	32,014	Acid + Frac
4703906161	Lower Huron-Marcellus	16	2008	2009	37,769	Frac
4703906150	Lower Huron-Marcellus	95	2008	2008	39,104	Acid + Frac
4703905966	Up Dev-Marcellus	114	2007	2007	50,626	Acid + Frac